INSTALLATION AND OPERATION OF BOILER CONTROL APPARATUS

BY

E. J. DURHAN

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INSTALLATION AND OPERATION OF BOILER CONTROL APPARATUS

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EDWARD J. DURHAN

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APPROVED:

George F. Gebhardt
Professor of Mechanical Engineering

H. M. Raymond
Dean of Engineering Studies

Dean of Caltural Studies

INSTALLATION AND OPERATION OF BOILER CONTROL

--- APPARATUS ---

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--INTRODUCTION--

The apparatus herein described was installed to afford a means of continuously indicating the nature and extent of the several losses in the operation of the boilers in the power plant of the Armour Institute of Technology. Since the conditions which influence the operation of the boiler vary continually, the phenomena of combustion must be continuously indicated in order to be properly controlled so as to give the maximum efficiency at all times.

The installation of this apparatus also affords a detailed study of the boiler and furnace losses under varying conditions of load, depth of fuel bed and draft. The instruments being both indicating and recording, a careful record of boiler performance can be kept and comparisons of daily, weekly or monthly records can be made with the object of increasing economy or reducing cost

of operation.

At present, the necessity of such instruments as herein described, has been felt more than ever because of the varying grades of coal received and a rapid means is necessary for determining the proper operating conditions.

The selection of the instruments has been given much thought with simplicity as an important consideration. To get the best attention and interest of the engineer, the instruments must be simple in construction, accurate, and require little repair. There is nothing that is more disheartening to the engineer than to have instruments which he is uncertain about and this leads to neglect and disuse of the apparatus.

--ACKNOWLEDGEMENTS--

The installation of the equipment described herein was undertaken with the approv-

al of G.F. Gebhardt, Professor of Mechanical Engineering and head of the Department of Mechanical Engineering of the Armour Institute of Technology, and was carried out under his supervision. To him the writer is indebted for many valuable suggestions and also for his assistance in criticizing and revising the manuscript. Acknowledgement is also due Mr.J.Allen, chief operating engineer, for his assistance and help in installing the apparatus.

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EXCESS AIR.

Before discussing the actual installation of the apparatus later described it is proper to investigate the magnitude of the losses common to the boiler and to see just what remedies should be applied.

Fig.(1) is a graphic representation of the average losses in the power plant of an industrial plant of from 1,000 to 2,000 horsepower. The process of power generation, its transmission and utilization, is shown as a stream of heat starting with the coal fired under the boiler and ending in the power utilized in a mill. The losses are shown as streams branching off to one side from the main stream. The first five side streams represent the boiler room losses, and altogether amount to 43% of the heat in the coal fired. The second loss, which is the heat carried away by the dry chimney gases, is the largest of boiler room losses. It amounts to 26% of the total heat in

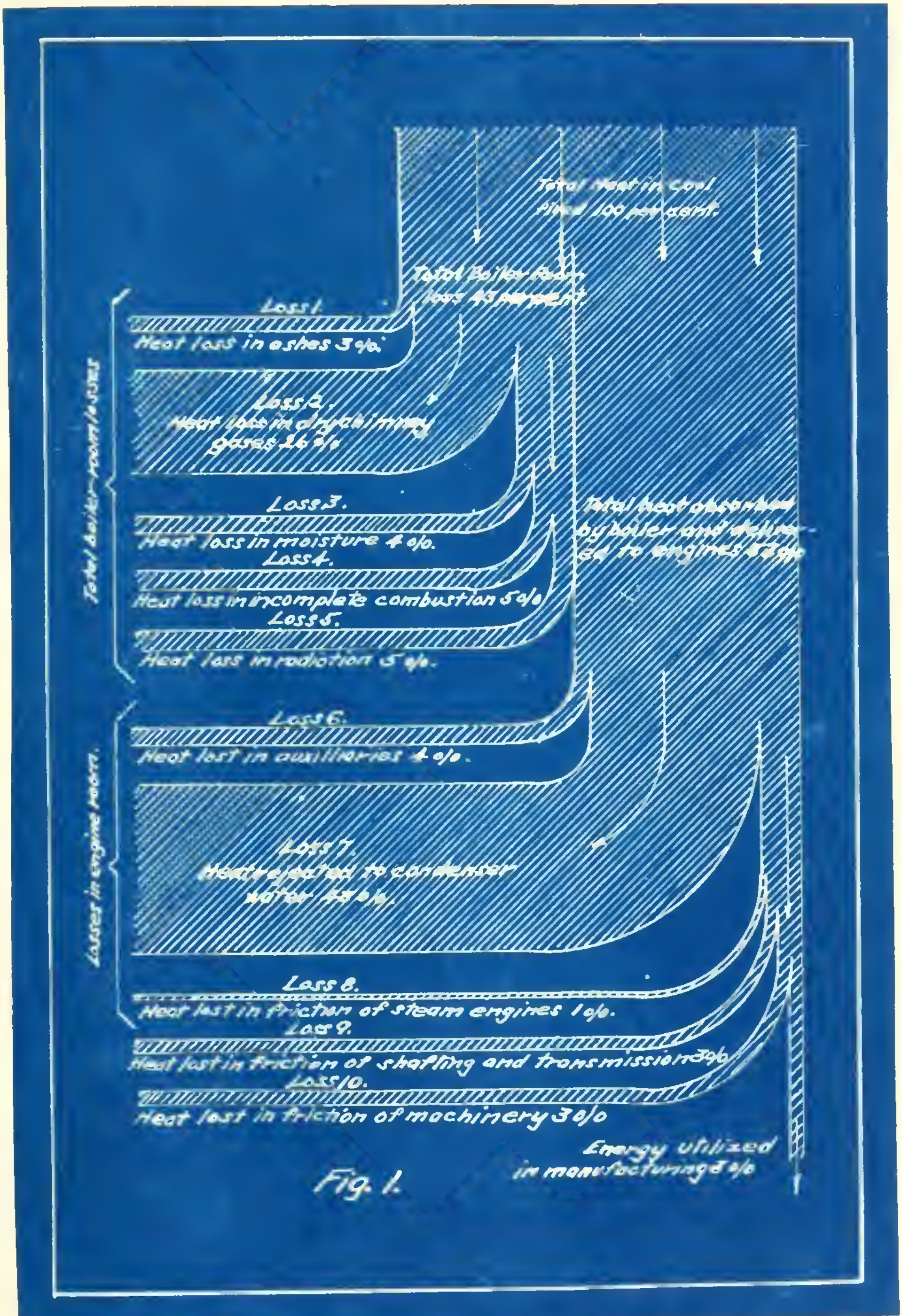

Loss 1.
Heat loss in ashes 3 o/o.
Loss 2.
Loss 3.
Heat loss in moisture 4 o/o.
Loss 4.
Heat loss in incomplete combustion 5 o/o
Loss 5.
Heat loss in radiation 5 o/o.
Total boiler-room losses
Loss 6.
Heat lost in auxilliaries 4 o/o.
Loss 7.
Losses in engine room.
Loss 8.
Heat lost in friction of steam engines 1 o/o.
Loss 9.
Heat lost in friction of shafting and transmission 3 o/o
Loss 10.
Heat lost in friction of machinery 3 o/o
Energy utilized
in manufacturing

Fig. 1.

the coal fired and is much larger than all the other boiler-room losses put together. It is this loss that, by the intelligent use of the instruments installed, can be greatly reduced without increasing any of the other losses, and is the only one which will be discussed at length here.

For the complete combustion of 1 pound of carbon, which is our most perfect fuel, 11.58 pounds of air are required for theoretically complete combustion. The air is taken into the furnace at atmospheric temperature and leaves the boiler at a temperature of about 500 degrees F. higher. It carries along with it all the heat that has been absorbed in raising its temperature 500 deg.F. Each pound of air or of the products of combustion absorbs approximately one-fourth of a heat unit per degree of temperature rise. Therefore, with a temperature elevation of 500 deg.F. each pound absorbs $\frac{500}{4}$, or 125, heat units.

If 11.58 pounds of air is used to burn 1 pound of carbon the products resulting from the combustion weigh 12.58 pounds. The quantity of heat carried out with the chimney gases for each pound of carbon burned then is 12.58 times 125, or 1572.5, heat units. If one pound of carbon contains 14,540 heat units, the heat carried out with the chimney constitutes $\frac{1,572.5}{14,540}$, or 10.81 per cent, of the total heat in the carbon. This is the minimum heat loss which is possible in burning pure carbon with the theoretical amount of air for perfect combustion.

In practice, to obtain perfect combustion an excess of air is required. With 30 per cent of excess air, the air required would be 11.58 $+$ .3(11.58), or 15.05 pounds, say 15.00 pounds. The products resulting from the combustion of 1 pound of carbon in this case would weigh 16 pounds. The quantity of heat carried out with the chimney gases for each pound of carbon burned then is 16 times 125, or 2,000 heat units, or

13.7 per cent, of the total heat in the carbon.

If instead of using 15 pounds of air to burn one pound of carbon, the fireman uses 31 pounds of air, the products of combustion weigh 32 pounds and the heat loss in the dry chimney gases is 32 times 125, or 4,000 heat units, or 27.4 per cent of the total heat in the coal fired. Thus it can be shown that the chimney losses increase almost directly with the amount of air used for the combustion of coal.

Combustion of coal is a chemical combination of its carbon and hydrogen with the oxygen of the air, the products of combustion are carbon dioxide and water vapor respectively. Air consists approximately of 20 per cent of oxygen and 80 per cent of nitrogen by volume. If all the oxygen that enters the furnace were used in combustion, the analysis of the products would show about

81.5 per cent of nitrogen and 18.15 per cent of carbon dioxide. The percentage of carbon dioxide would not be as high as the percentage of oxygen in the air admitted into the furnace because some of the oxygen combines with the free hydrogen of coal and forms water vapor which is condensed and therefore does not appear in the analyses of the gases.

If only one-half of the air entering the furnace is used in the combustion of coal the analysis of the products shows about 9 per cent of carbon dioxide and 10 per cent of free oxygen--thatis, about one-half of the oxygen appears in the form CO_2 and the other one-half as O_2. The CO_2 is not exactly equal to the O_2, because a small part of the oxygen used in combustion combines with the hydrogen of the coal and is condensed as water. Thus the CO_2 content of the flue gases shows what proportion of the air entering the furnace is actually used in the process of combustion and the oxygen content

shows what proportion is in excess of the amount actually used.

Besides increasing the chimney losses, the use of a large excess of air reduces appreciably the horsepower that can be developed with a given boiler installation. This feature is an important one in case the boiler plant is heavily loaded.

It is apparent then, that if the chimney losses are to be low, and the horsepower developed by the boiler high, the weight of air used must be at a minimum or as low as completeness of combustion will permit; 15 pounds of air to 1 pound of coal, if properly introduced into the furnace and with careful firing gives practically complete combustion in most boiler furnaces. It is just this information than the analysis of the flue gases furnishes (the quantity of air being used for combustion).

The factors which enter into the elimination of waste in steam boiler practice are many, but;

sifting the essentials from the non-essentials we have the following items which require study and adjustment:

1. Clean boilers.
2. Tight settings.
3. Skillful Firing.
4. Knowledge of the chemical composition and physical properties of the coal used.
5. Furnace adapted to the fuel used.
6. Draft regulation.
7. Continuous knowledge of the percent of CO_2 contained in the flue gas and its temperature at the point it leaves the boiler.

CLEAN BOILERS.

From the many tests made on the transmission of heat into steam boilers and the effect of scale and soot on the coefficient of heat transmission, it will be found that clean boilers are absolutely essential toward higher economy.

These deposits need not be considered as long as the boiler surface is capable of transmitting the heat generated, and there is no decrease in efficiency, as is the case with boilers running under rating. But with boilers running at or above rating the effects increase rapidly. The boiler surface being incapable of transmitting any more heat to the water, the excess heat tends to raise the temperature of the metal above that of the steam causing the tubes and sheets to burn out or bulge with a corresponding decrease in the life of the boiler. The excess heat, or that above the amount used for steam making, also passes off into the flue, increasing the temperature of the dry-chimney gases with a resultant decrease in efficiency.

--TIGHT SETTINGS.--

Tight settings are the exception rather than the rule. This is one of the most prolific causes of low boiler efficiency. From 20 percent to 30 per cent of the air passing throùgh the

fire and furnace is drawn through numerous cracks with the greater number nearer to the 30 per cent limit. Since the air so entering cannot aid combustion but is all heated to the stack temperature, it follows that 25 per cent air infiltration will increase the heat wasted by the chimney by just that amount. It will later be seen that this is also a condition which seriously effects draft indication from being used separately to indicate boiler efficiency.

The settings of all boilers should be kept air-tight. Too frequently no attention is given to this feature. Leakage usually occurs through cracks in the walls of the settings or where masonry makes a joint with the metal parts of the boiler. The walls themselves if free from cracks and made of good bricks properly laid in good mortar, are fairly air tight with the usual pressure difference on the two sides. Cracks in the walls

and the openings of joints are caused by difference in expansion due to variations in temperature. They cannot be prevented, but when they form they should be stopped.

Another common source of leaks in small boiler plants is badly fitting doors in the boiler. Some of these doors seem to have no provision to keep them closed; a brick is set against them to keep them from flying open. At some plants the cast iron frame ofthe ash door is loose from the wall and allows considerable air to leak in. There may be many leaks in a boiler setting, but those mentioned are typical ones. A good way to find a leak is to hold a candle or torch to the suspected place, and if there is a leakage the flame is drawn in.

All boilers with a brick setting should be frequently examined for leakage, for, as a rule there is always plenty to be found. Every leak, no matter how insignificant it may ap-

pear to be should be promptly stopped. Time spent in keeping a setting tight is time well spent.

--SKILLFUL FIRING--

The fireman is the man in charge of the boiler and it is his duty to supply the necessary quantity of steam at the desired pressure. With only the pressure gauge as a guide, he strikes some relation between draft, thickness of fuel bed, and rate of driving which will give him the capacity regardless of economy. With the skill that he possesses, he will prevent holes from accumulating in the fire by observation and see that no unconsumed coal is carried over the end of the grate. If the fire tends to draw away from the grate, he will decrease the speed and increase the thickness, or adjust the dampers. If the fire tends to pass over into the ash pit, the fuel feed is too fast or too thick,

or the furnace is given insufficient draft. For economical firing, the fuel should be consumed upon reaching the rear turning point. The back end of the grate should never be bare of live coals. The fires are to be kept clean and free from clinkers.

This is what is ordinarily termed skillful firing and is all that can be expected of the fireman with the pressure gauge and his judgement as his only guide. Judging the combustion by the eye requires an exceedingly skillful fireman and his judgement at best is only good when insufficient air is being supplied which is seldom the case. It is doubtful if there is a fireman who can tell any difference in the combustion between 100 per cent and 200 per cent air excess.

But by including in the equipment of the fireman a full compliment of indicating instruments, his skill can be still further displayed. By keeping the CO_2 as high as possible

without an increase of CO and the temperature in the flue as low as possible and studying the relation of draft to these, he will make a step toward higher economy.

A fuel bed resistance should be obtained such that the normal amount of coal can be burned without excessive draft. If a thinner fire than this is used there is a greater probability that there will be holes or thin places in the fuel bed, forming pathes of least resistance through which an excessive amount of air passes with a conseqent decrease in efficiency. On the other hand if the thickness of fire is materially increased it becomes necessary to use more draft in order to maintain the load. The increased draft causes an increase in air leakage through the setting, etc. thereby causing the efficiency to drop. This reasoning is based on the assumption that there is no more CO formed when using a thicker bed than with a thinner one. There is a well mark-

ed thickness of fire for each load which gives the maximum efficiency and as the load decreases the depth also becomes less.

For each load, or rate of combustion, a given amount of air is necessary. If the fuel bed is too thick, or dirty, it requires a heavy draft, with a consequent increase in air leakage through places other than the fire, thus causing a loss in efficiency. If it is too thin the draft may be reduced, but in this case the air leakage occurs through the fuel be itself with the same result as before.

Temperature measurements of the gases in the flue give a good indication of the condition of the boiler. High temperatures in the stack may indicate broken down baffles which can be quickly corrected before the loss becomes appreciable. A rise in temperature will also indicate dirty boilers and scale formation showing a decrease in heat transmission. On the other hand a decrease in temperature from the normal

may indicate an air excess and in conjunction with CO_2 can be verified.

KNOWLEDGE OF THE CHEMICAL COMPOSITION AND THE PHYSICAL PROPERTIES OF THE COAL USED.

Knowledge of the chemical properties and the physical properties of the coal used is necessary not only for determining the proper design of furnace, etc., but it is valuable in every day operation just as well. Every material change in the chemical and physical properties of the coal requires a change in the method of firing, the frequency of cleaning the fire, the strength of draft, etc. A correct knowledge of the chemical composition and physical properties of the coal used will therefore be of material assistance in maintaining a high efficiency in every day practice.

To calculate the amount of air required for a given coal and to ascertain the economy of combustion, the ultimate analysis of the coal used is essential. If the coal delivered to the plant

comes from a particular field and varies only slightly, an exact ultimate analysis is desirable. But where the supply changes constantly and comes from different fields the expense of having each coal analyzed is out of the question. The time involved for such an analysis also enters into the consideration. The coal may be consumed and a new supply from a different field being fed into the furnace before the results of the analysis are obtained.

By the use of the many analysis published by the Bureau of Mines and a proximate analysis of the coal used, which requires only a short time, a calculated value for the ultimate analysis can be obtained which agrees very closely to the actual value. It has been found that from a given locality coals have practically the same analysis when expressed on a "moisture, ash, and sulphur free" basis. All that is necessary then is to know the locality from which the coal comes and a proximate analysis made thereof to compute

the ultimate analysis.

--FURNACE ADAPTED TO FUEL USED--

Every engineer knows that the furnace and grate bars must be adapted to the kind of coal available, if good results are to be realized. It may, and generally does require the services of a combustion expert to determine the grate and furnace construction best adapted to burning a given fuel; but when these conditions are once determined there is no good reason why they should not be maintained in every day practice.

At present the conditions are such that the coal for which the furnace is adapted, is not always available. Under such conditions the only thing to do is to burn coals as effectively as skillful operation permits until the proper fuel can again be obtained.

The loss of fuel through grates varies with the coal and grates and may be considerable. It may be so great as to offset all the

other advantages gained in the fuel, more particularly the price. A careful record should be kept of this item and compared with the different coals used.

The material that is removed from the ash-pit is called "refuse" and that part that is neither combustible nor moisture is properly called "ash". Weighing the coal as fired and also the amount of refuse removed is essential to information leading to economy. The weight of this refuse is commonly, but incorrectly, called ash in the coal. Under the best conditions a certain amount of combustible will pass through the grates. If a systematic coal analysis is made, the difference between the per cent of refuse and the per cent of ash by analysis is the per cent of coal lost through the grates. The heat value of the combustible in the refuse is usually higher than that of the coal and a separate calorimeter test may be made.

--DRAFT REGULATION--

Draft regulation is a most important factor in the proper operation of a steam-boiler and is probably the least understood. In the steam-boiler furnace the hot fuel is made burn by passing a current of air through it. The air so supplied serves a twofold purpose, supplying the necessary oxygen and carrying away the gaseous products of combustion. In order that the boiler may absorb the heat generated by combustion and contained in the gaseous leaving the fuel bed, the gases are caused to flow along the heating plates of the boiler and to impart heat to them by coming into contact with their surfaces. The stronger the current of air through the fuel bed the higher will the rate of combustion be; and, the stronger the current of gases over the heating surfaces the faster the boiler will absorb heat. It becomes quite evident that the motion of air and of the gases of combustion is very essential to the operation of a furnace and boiler. The

motion of gases is produced by an excess of pressure at any point over that at any other point toward which the gases are flowing; the greater the pressure difference the higher the velocity of flow.

Draft is the force which impels the air through the fire and the products of combustion through the boiler and up the chimney. Draft, whether natural forced or induced, is manifested by a difference in pressure. The effective draft is the difference in pressure between the air under the grate bars and the gases leaving the boiler; it is composed of a part, viz., the furnace draft and the boiler draft. The former is the pressure difference between the ash pit and the furnace, and the latter, the boiler draft, is the pressure difference between the furnace and the uptake.

There are three ways of producing such differences of pressure as will cause gases to flow through the fuel bed and boiler ----

(1) by chimneys, (2) by exhausting gans between boilers and chimneys, and (3) by pressure fans supplying air under the grate.

The use of high chimneys is most common. They reduce the pressures inside their bases so that the greater pressure of the atmosphere outside pushes air through the fuel bed and the gases of combustion through the boilers into their bases. The reduction of pressures is due to the fact that the gases of combustion expand when heated, in consequence of which the chimneys contain smaller weights of gases than they would if chimneys and gases were cold. We then have the weight of a column of hot gases in the chimney pressing against the gases in the uptake, and the weight of a column of air of the same dimensions and at atmospheric temperature pressing against the air in the ash pit.

Referring to Fig.(2), let w be the weight ofthe column of hot gases in the chimney, and W the weight of a column of outside air of the same dimensions; then the difference(d) between the

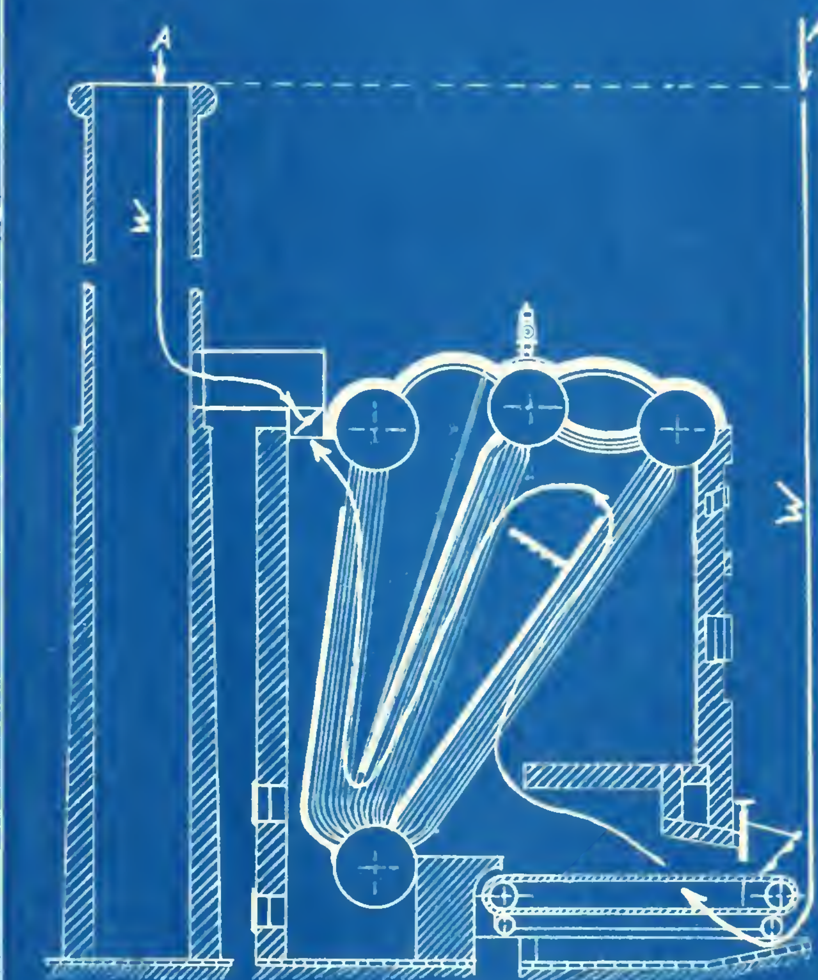


Fig. 2.

pressures in the ash pit and the uptake will be the difference between the weights of these two columns when both have unit area of cross section, or $d=W-w$.

The same equation will be obtained if we include in the calculations the weights of the columns of air above the chimney and above the aforementioned imaginary column of cold air outside the chimney. Let the weights of these columns be A (see Fig.2.); then the total weight pressing against the ashpit door is $A+W$ and the total weight pressing against the gases in the uptake is $A+w$. Therefore the difference, $d=A+W-(A+w)=W-w$, as before.

As a result of this difference of pressure the outside air pushes the furnaces gases into the chimney and through it into the open atmosphere. The air which has pushed through the fuel bed into the furnace is partly modified by the combustion, which produces more furnace gases, which are in turn pushed out through the chimney

into the open air.

It is evident that the hotter the gases in the chimney the more they are expanded and the lighter they become, and the greater is the difference of gas pressure between the front of the furnace and the base of the chimney; also the higher the chimney the greater is the difference of pressure.

The heat energy left in the column of gases escaping from a boiler is not entirely wasted, as a part of it is used in keeping up the continuous current of gases. By raising the temperature of the gases the same difference of pressures between the uptake and the front of the furnace can be had by a low chimney as by a high one, although such a method would not be economical. Anything which reduces the temperature of the gases while in the stack reduces the magnitude of the pressure difference between the chimney base and the furnace doors; on this account less coal

can be burned and less steam generated. It follows that a steel stack without any brick lining on the inside is, on account of the high thermal conductivity of the steel, not as efficient as a brick one, provided the latter is absolutely tight, as is seldom the case.

Another method of reducing the gas pressure in the uptake of the boiler setting is by an exhaust fan. Usually it is said that the exhaust fan sucks or pulls the gases through the boiler; in reality no such action can occur. The blades of the fan push the gases out of the casing, thereby reducing the pressure in it below that in the furnace; the excess of pressure in the furnace then pushes other gas through the boiler into the space of reduced pressure inside the fan casing, and so the current continues.

Another way of producing as excess of gas pressure under the grate over that in the uptake is by connecting a pressure blower or fan to the

space under the grate, so as to increase the pressure therein above that of the atmosphere. In some cases the whole fireroom is put under pressure. This method is ordinarily termed "forced draft", in contradistinction to the term "induced draft". There is however no essential difference between the two. Occasionally they are used together and sometimes all three methods are used.

The drop of gas pressure from one part of the boiler setting to another varies as some power of the resistance to the flow of gases. Thus a great drop from ash pit to furnace indicates a high resistance in the fuel bed, and a great drop from the furnace to the uptake indicates a high resistance to the flow of gases through the boiler proper.

The boiler draft varies directly with the volume of gas coming from the furnace, hence for the same rate of combustion it varies inversely as the percent of CO_2 in the flue gas,

and for the same per cent of CO_2 it varies directly as the rate of combustion.

The furnace draft depends on many things: (a) the kind of coal; (b) the rate of driving; (c) the thickness of fire; (d) the conditions of the fire; (e) the formation of clinker, etc., from all of which it is evident that the proper regulation of draft requires close and intelligent observation and judgement.

--CONTINOUS KNOWLEDGE OF CO_2 AND TEMPERATURE--

The only correct and adequate way of controlling the process of combustion with a view to higher boiler efficiency is by a systematic continous knowledge of the composition of the gases of combustion and in connection, the stack temperatures. These two items constitute a measure of the heat wasted up the chimney and a lack of such analysis is the principal reason why the higher boiler efficiencies practically demonstrated by expert tests are never attained in every day practice.

Maximum efficiency results when the necessary amount of fuel is completely burned with a minimum excess of air, and the flue gases leave the boiler with the lowest temperature consistent with the rate of driving.

Without adquate means of knowing when this condition is obtained, it is impossible for even the most expert fireman to obtain maximum efficiency. The per cent of CO_2 is a correct index to the volumn of excess air, and hence the total weight of the flue gas per pound of of coal burned multiplied by its specific heat and temperature, ie., the difference in temperature between the air in the boiler room and the escaping gas, gives us the heat wasted up the chimney for every pound of coal burned. An instrument which continuously indicates and records the CO_2 contained in the gas, as well as the temperature of the escaping flue gas, is therefore essential for higher economy.

A continuous record of the temperature of the escaping gas, although less valuable as a control of boiler efficienty, is nevertheless of great importance. The temperature when recorded with the CO_2 simultaneously will give the most valuable information as to the condition of the operation of a boiler. The temperature of the flue gas is but slightly effected by excess air supplied to the furnace, hence cannot be directly controlled by the fireman. It depends (a) on the ratio of the heating surface of the boiler to the grate area, if the boiler has insufficient heating surface the gases will escape at a high temperature, (b) on the condition of the heating surface, the stack temperature necessarily rises as the boiler becomes dirty, and the temperature record is very valuable in revealing this condition, (c) on the rate of driving, the harder a boiler is driven, the higher the stack temperature, and that is the principal reason why economy suffers when a boiler is driven at an excessive rate, (d) the

stack temperature is markedly effected by air infiltration, while an excess of air supplied to the furnace but slightly, and that in an upward direction, the air which enters through pores, cracks and crevices of the setting materially reduces the temperature. Thus we see that the stack temperature alone may give very misleading information, but in conjunction with CO_2 gives valuable information about the condition of the boiler itself as well as the boiler setting.

--INFLUENCE AND IMPORTANCE OF DRAFT.

A third source of important information relates to the draft conditions. There is one factor which affects the draft to a greater extent than all others and that is the per cent of CO_2 in the flue gas. All other conditions remaining the same the higher the per cent of CO_2 the better the draft. This is due to the fact that the volume of a flue gas varies inversely with the per cent of CO_2 and the greater the volume of a gas crowded through a given chimney the

poorer will be the draft. Raising the per cent of CO_2 to twice its original amount more than doubles its capacity. There is then a definite relation between the CO and the total available draft as well as boiler efficiency, hence a chimney should be releived of its illegitimate burden due to low CO_2 before considering other means of augmenting the draft.

The total effective draft is what is ordinarily measured by the draft gauges and if all other conditions remained constant it would be an index to the volume of gas passing through the boiler and, with a perfect setting, to the rate of combustion, hence the rate of driving, and would be useful in regulating the steam production.

But since the conditions, especially those of the furnace, upon which the effective draft necessary to maintain a definite rate of driving depends, vary continually, it is evident that the effective draft must also vary, and cannot be a true index to the rate of combustion.

A draft gauge applied to the furnace shows the resistance through the ash pit door, the grate, the ashpit and the fire. With a given effective draft, if the ashpit doors are partially closed the furnace draft is increased, but the rate of combustion is decreased. The same effect is produced by produced by the accumulation of ashes, the formation of clinker, and the coking of coal. The furnace draft is thus increased by at least four distinct causes, all of which tend to check the rate of combustion. On the other hand, if the fire is sliced, the furnace draft is decreased and the combustion is increased, and still more is this the case when the fire has been cleaned. It is clear, then that the readings of a draft gauge in the furnace cannot be relied upon as an index to the rate of driving, much less to economical operation.

A draft gauge connected to the space above the fuel bed, however gives useful information as to the condition of the fire to a fireman who understands the significance of its indications.

Thus, after cleaning a fire, if the pressure drop from ashpit to fuel bed to too small the fireman may be sure that there are holes in the fire, or that it is too thin; or, if the pressure drop is too great, it is probable that the fire is too thick. A gradual increase of drop through the fuel bed, after the fire has burned for some time, is an indication of the accumulation of clinker next to the grate. Of course, a drop through the fuel bed, is adjudged high or low only after considering it in connection with the total drop through the whole apparatus. It may happen, in the same apparatus, with the same coal from the same bin, and with the same total pressure drop, that much less coal is burned and a smaller amount of steam produced on one day than on another, although the pressure drop through the fuel bed is higher on the day of smaller steam production. The explanation may be drawn out as follows: When coal is taken out of the

side and bottom of a bin, the large pieces tend to flow out first, leaving the smaller pieces and dust in the far corners, which stay there to the last, until all the coarser coal has been consumed. When burning the finer coal, the resistance to the passage of air through the fuel bed is greater, and this greater resistance causes a higher pressure drop--that is, a higher "draft" above the fire; simultaneously the smaller air supply results in a lower rate of combustion and a smaller steam production.

--RELATION OF DRAFT TO CO_2--

From the foregoing somewhat detailed analysis of draft and its relation to combustion it would appear, 1st., that the total available draft, ie., the chimney draft, is affected favorably by wasteful boiler operation due to low per cent of CO in the flue gas, but that a knowledge of the chimney draft and temperature are of no great value as a check on economical operation of a boiler plant; 2nd. that the effective draft upon which depends the rate of

combustion is itself dependent on the variable conditions of the furnace, that it cannot be relied on as a guide by which to regulate combustion; 3rd., that furnace draft due to ever changing conditions must necessarily vary if a definite rate of combustion is to be maintained, and is therefore useless as a guide, but is of greatest value as an index to the condition of the furnace, provided we have a true index to the rate of combustion. Fortunately, such an index can be made available.

Boiler draft, as already stated, is the resistance offered to the products of combustion passing through the boiler, which is measured by the difference between the furnace draft and the effective draft. In any given setting the boiler draft depends on only two factors, viz., the rate of combustion and the per cent of CO_2 in the flue gas. For a given per cent of CO_2 the higher the boiler draft the greater the rate of combustion. And for any given rate of combustion

the higher the per cent of CO_2 in the flue gas, the boiler draft becomes a true index to the rate of combustion. This is most important, since such an index shows whether each fireman is doing his proper share of the work, and whether every boiler is being driven to its proper capacity. The steam flow meter is also a useful indicator for this purpose.

To get the proper solution of the problem of attaining and maintaining maximum boiler efficiency, it must be realized that combustion is a chemical phenomena, which can be diagnosed and controlled only by chemical means. And it is for this reason that a CO_2 meter, pyrometer and draft gauges are indispensible if maximum efficiency is to be attained and maintained.

PART III.---THE PLANT.

13.Boilers and Stokers.

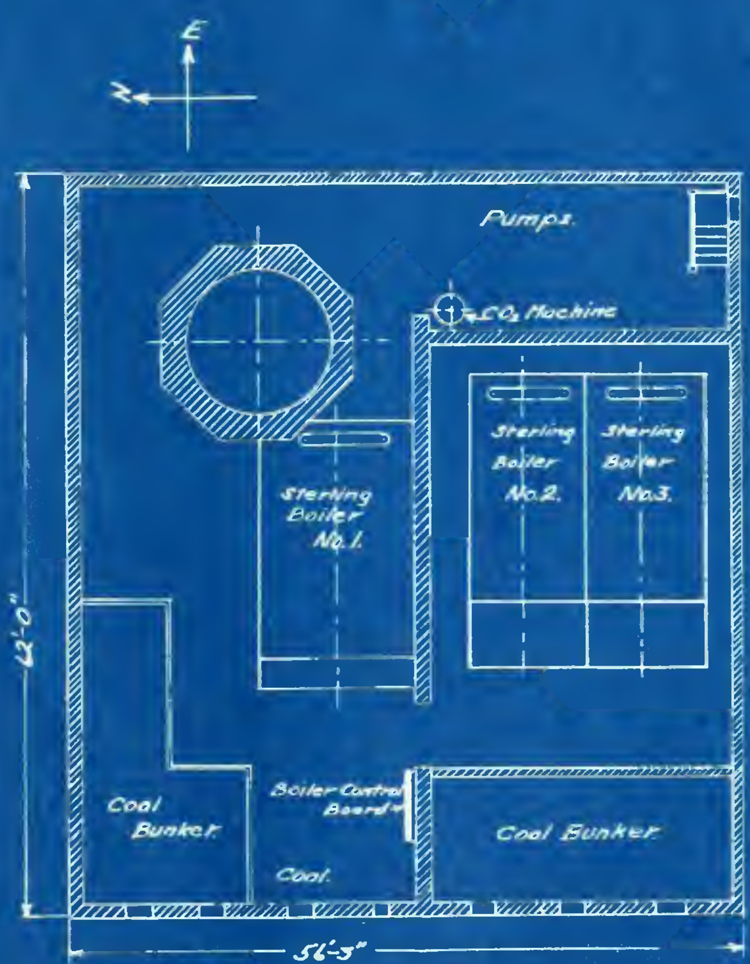
14.Boiler Control Board.

THE BOILERS AND STOKERS.

The boiler on which the instruments were installed is one of three Sterling boilers in the plant of the Armour Institute of Technology. It is designated as boiler NO.1., Fig. (3). Boilers Nos. 2 and 3. are located to the south of No.1. and are separated by a heavy wall. Boiler No.1. is the newest of the set of three, having been installed in 1902 and is the only one used except in cases of excessive demand for steam or shutdown.

Boiler No.1. is rated at 350 horsepower and is used to supply steam for heat and power to the Institute and surrounding flat buildings. A cross section through the boiler is shown in Fig.(4). From Fig.(4) it may be seen that the baffling is of the standard type. The location of pyrometer and sampling tubes is also shown.

The stokers are of the chain grate type having an active grate surface of 90 square feet, and were built by the Green Engineering Company. The draft is produced by a brick chimney 175 ft.



General Layout of Boiler Room at Armour Institute of Technology-Chicago.

Fig. 3.

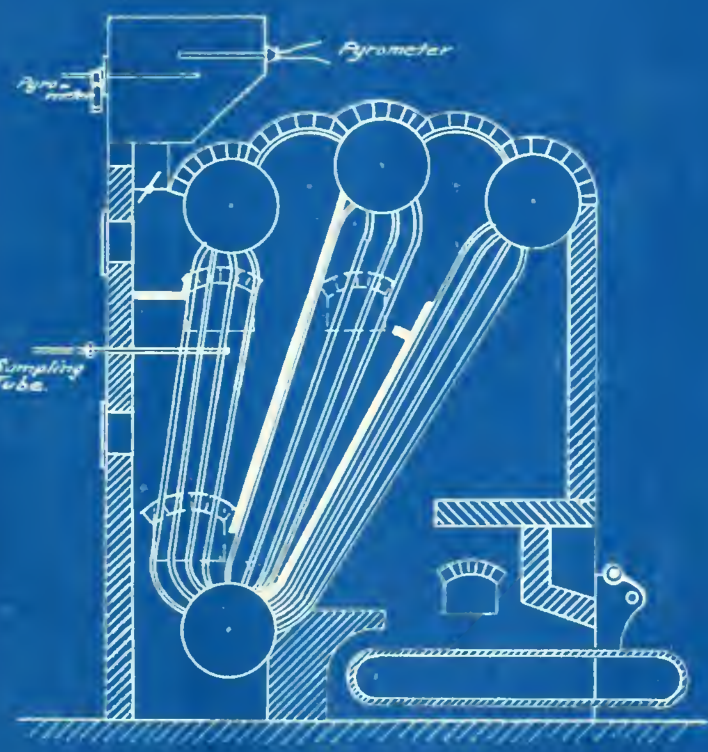


Fig. 4.

high, having an internal diameter of 7 ft. In addition, a small forced draft fan is placed in the ashpit.

--THE BOILER CONTROL BOARD.--

This board was designed to facilitate the grouping of all the instruments to the boiler and located so as to be in direct view of the fireman. The location of the board is as shown in Fig.(3). being placed on the north wall of the coal bunker for boilers Nos. 2 and 3.

The board and equipment can best be explained by reference to Fig.(5). The frame is made of 2 inch by 3 inch angle iron with mitered corners and 5 ft.9 inches by 3 ft. in size. Cast iron brackets are provided to keep the frame about 10 inches from the wall to allow for piping etc., to the instruments. The frame is provided with three wooden panels and grooved so as to be flush with the front edge of the angle iron. The panels areeasily removed.

The center panel contains only the steam flow

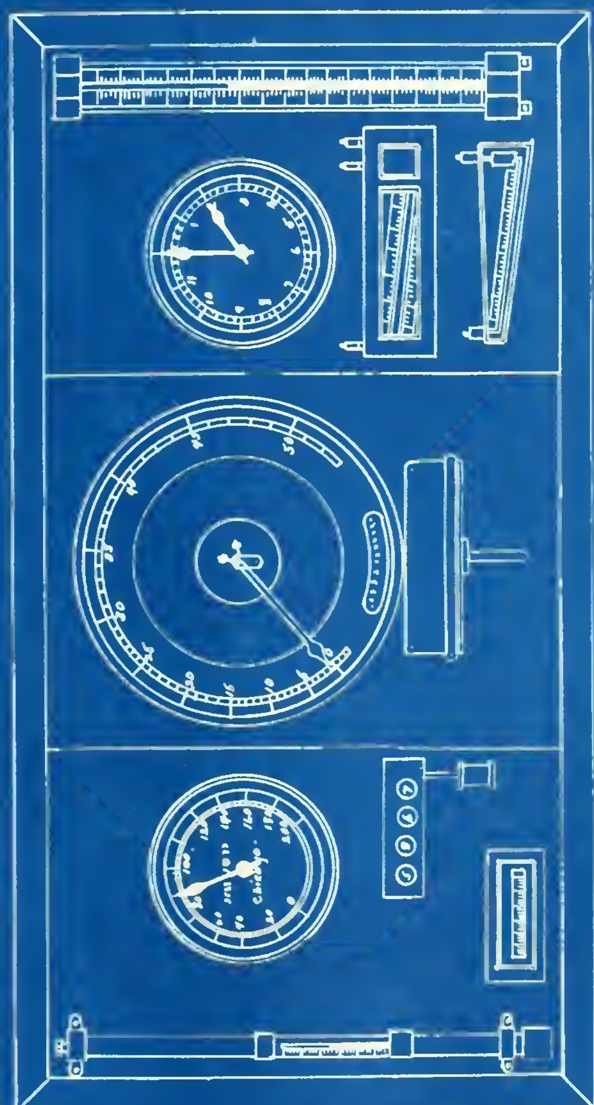


Fig. 5.

meter and is indicating only. This meter shows the amount of steam delivered at any time by the boiler. On the left panel near the top is a steam gauge and on the right panel and in line with the other two instruments is the clock. Below the clock on the right hand panel are the draft gauges. The upper gauge measures the draft between the ashpit and fire and between the fire and damper while the lower gauge measures the total draft between the ashpit and damper. To the right of the clock is located a mercury column gauge to indicate the difference in head between the throat and upstream of the venturi tube. This indicates the amount of water being fed to the boiler. To the left of the steam gauge on the left hand panel is located the CO_2 indicator which continuously indicates the amount of CO_2 in the flue gases. At the bottom of the panel is a millivoltimeter which gives the temperature of the gases an leaving the boiler. Between the steam gauge and millivoltmeter is located a small electrical count-

er which is calibrated to give a record of the coal consumed. Thus it is seen that the equipment is complete in every detail to efficiently control the combustion.

PART IV.---DESCRIPTION OF APPARATUS.

15.Uehling CO_2 Meter and Pyrometer

16.General Electric Steam Flow Meter

17.Venturi Water Meter

18.The Draft Gauges.

---THE UEHLING CO_2 MACHINE AND TEMPERATURE RECORDER--

The principles upon which the Uehling CO_2 Machine are based may be best explained by reference to Fig.(6.). If two apertures, A and B, form respectively the inlet and outlet openings of chamber C, and a uniform suction is maintained in the chamber C' by aspirator D, the action will be as follows:

Gas will be drawn through B into the chamber C', creating suction in chamber C, which in turn causes gas to flow through A. The velocity with which the gas enters through A depends upon the suction in C, and the velocity at which it flows out through B, depends upon the excess of suction in C', over that existing in C, that is, the effective suction in C'. As the suction in C increases, the effective suction must decrease, and hence the velocity of gas entering at A increases, while the velocity of gas passing out through B decreases, until the same quantity of gas enters

Fig. 6.

Fig. 7.

at A, as passes out through B. As soon as this occurs no further change of suction takes place in the chamber C, providing the gas entering A, and passing out at B, be maintained at the same temperature.

If from the constant stream of gas, while flowing through C, one of its constituents is continuously removed by absorption, a reduction of volume will take place in chamber C and cause an increase in suction, and consequently a decrease in the effective suction in C'. Hence the velocity of the gas through A will increase, and the velocity through B will decrease, until the same quantity enters A. As is absorbed by the reagent plus that which passes out at B.

Thus every change in volume of the constituents absorbed from the gas, causes a corresponding suction in chamber C. The increase of vacuum in chamber C, as shown by the manometer p, is a correct measure of the volume of gas absorbed, and in the Uehling CO_2 Machine, is utilzed to

indicate and record the per cent of CO_2.

The practical form of the instrument which embodies the principle described, may be explained by reference to Fig.(7) and (8) in which the letters and numbers correspond. The instrument is in reality an open pipe line in which pressures (below atmospheric) are measured at different points. The line has been given its present shape for the sake of compactness. If suction iscreated by any means at C'', Fig. (7), gas will tend to flow through the line, entering at filter D. At manometer M the pressure on the line is measured. The gas passes through valve J, and the pressure is measured again at S. Here it meets an anxilliary suction, C, and tends to divide, the division depending on the relative suctions.

Thence the gas passes through valve 2, through the small cotton filter F, through the steam pot X where it is heated to a constant temperature and then meets a high resistance in the form of the orifice A. The gas next passes through the caustic N, after

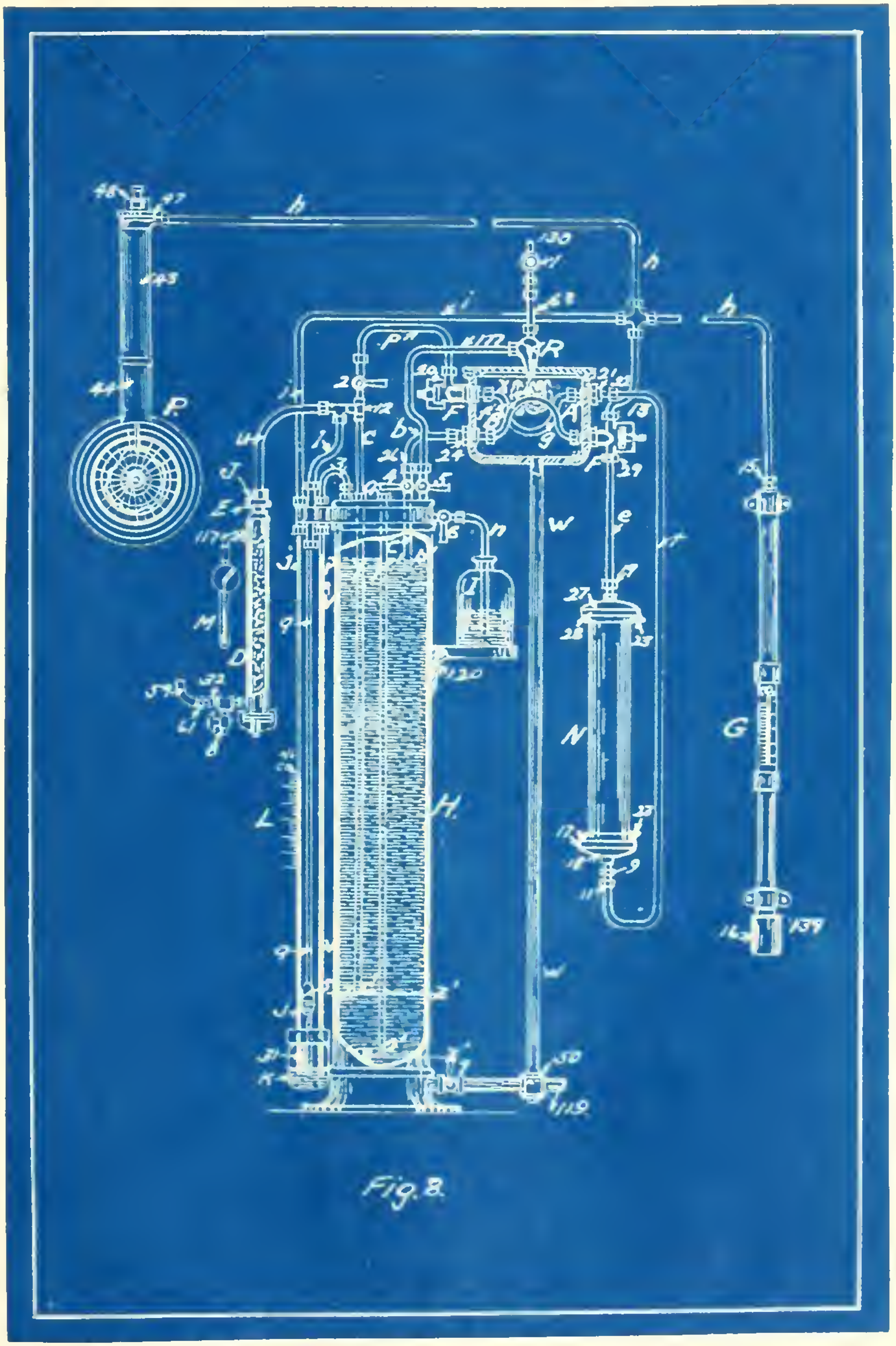


Fig. 8

which the pressure in the line is again measured, this time by L, G, and P., L, G, and P, being the water scale at the front of the instrument, the boiler-room indicator, and the chart recording gauge, each measures pressure. The gas now passes through another small cotton filter F', again through the steam pot X, where it assumes again its original constant temperature, then meets another high resistance at orifice B. Finally it passes through valve 4 out through the suction.

The gas must be brought to the instrument under a constant tension and must be drawn through the apertures by a continuous and uniform suction. This is fulfilled by the Regulator H, Fig.(8). This consists of a cylinder H, 8 inches in diameter and 5 feet high, filled with water as shown, into which project 2 long tubes aa' and cc' and a short tube bb'. The tube aa' is open to the atmosphere at a and extends within a few inches of the bottom of the cylinder. The end of the short tube bb' is exactly 48 inches above the lower end of aa'. The

lower end of cc' is just 6 inches above the lower end aa'. The cylinder H is filled with water so that the tube bb' is submerged several inches.

The method of obtaining the suction C and C" can be seen from Fig.(8). If valves 8 (to let in air), J,2, 4 are open and valve 5 is slowly opened, a suction is produced, and atmospheric pressure on the water in H is lowered. As the suction becomes great enough, air flows in through the center tube a and relieves the suction. At the same time air flows in through the line, owing to the suctions C and C". The pressure of the suction is registered by tube v. Now if manometer S is held constant by valve 5, a certain flow of gas is induced through the recording line; and the gas is kept at a constant temperature by being heated at two points just before it passes through its highest resistance. L, G, and P will be registering a pressure varying between C and C", depending on

the resistance on either side. If, for any reason, L shows a higher level at one time than another, the indication is that the pressure is nearer to C", that is, that the resistance at A or F or N has increased; if L shows a lower level at one time than at another, the resistance F' or B has increased. If gas containing CO_2 now flows through the line it will give up part of its volume at N. This condition could be considered as the resistance between L and C" being decreased, is that the level of the liquid at L will be higher. And so it is necessary only to mark on a scale at L, G, Or P the level of the liquid for a gas of a known, CO_2 content.

The condition that the gases must be at a constant temperature while passing through the calibrated apertures, is brought about by placing both apertures A and B in a chamber X which is kept at a uniform temperature of 212°F. by the exhaust steam of the aspirator R, which is permitted to escape at atmospheric pressure through the pipe WW.

In order to keep the apertures perfectly clean, a large filter is placed at the source of the gas supply, together with secondary cotton filters D

and the small filters F and F' before each aperture by which the gas is perfectly cleaned and the apertures protected from being fouled.

Leakage is guarded against by making all connections of drawn copper tubing, connected by knife-edge joints and carefully tested. Chamber C is composed of the pipe t, absorption chamber N, the pipe e, filter F' and pipes h, i, connected to filter F'. Branch i is connected to the manometer tube jj, and the recording gauge P and indicating gauge G are brought into communication with chamber C through the pipes h. The manometer tube jj and indicator G and recording gauge P are so calibrated that the suction between aperture A and B, chamber C, can be read off in per cent CO_2 contained in the gas.

The CO_2 to be measured must be completely absorbed after the gas passes through A and before it passes through B. For this purpose, the absorption tube N is provided in which are placed cartons of natron, for dry absorption.

The Pyrometer operateson the same principle as the CO_2 Machine. In the latter the volume of gas entering through aperture A is reducing by absorbing a portion (the CO_2) of gas before passing through aperture B, the gas passing through both apertures at the same temperature, whereas in the pyrometer the gas (air) passes through aperture A at the temperature to be measured and through B at a constant temperature (212^o) and the column qq responds to the change in temperature at which the air enters aperture A.

To insure that the air enters aperture A at the temperature to be measured A is located at the end 102 of a small tube, 101, which is placed in a larger tube, 100, Fig. (9) which protrudes into the stack or chamber, the temperature of which is to be measured. Tube 100 is closed at one end but is in communication with the atmosphere through filter 98 at the other end. The small tube reaches too near

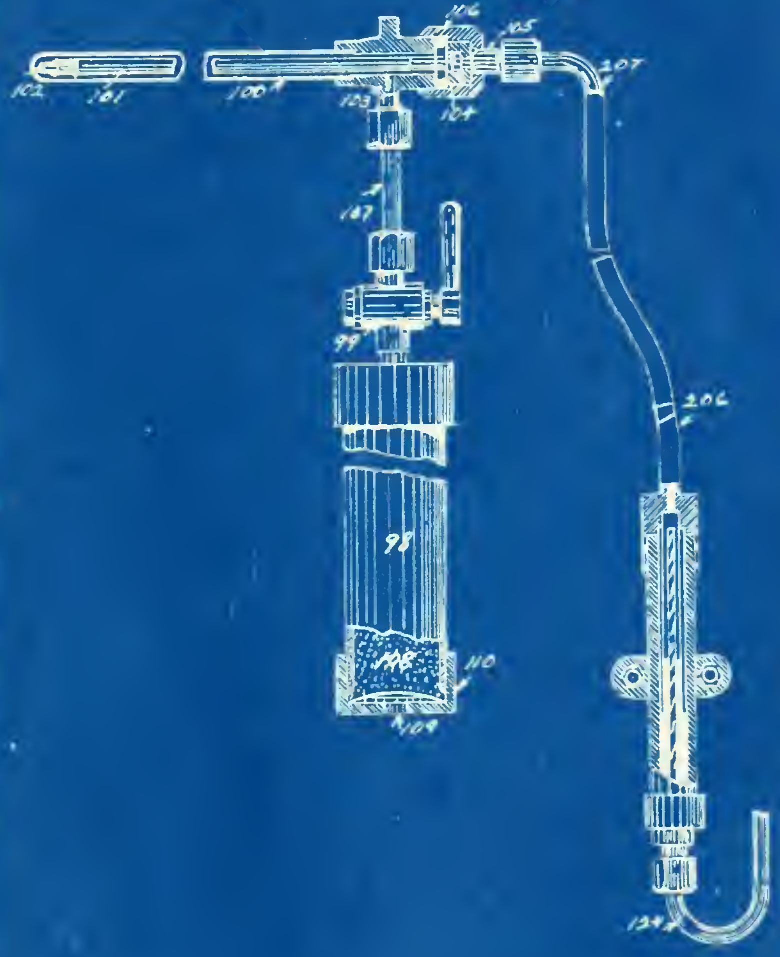


Fig. 9.

the closed end of tube 100 and is directly connected with filter F on the main instrument by 3/8 inch copper tube 124. The combination of tube 100 with inner tube 105 is called the fire tube.

It is necessary that the hot flue gases be cooled and for this purpose a condenser is provided as shown in Fig.(10). The condenser is made of wrought iron pipe and functions as follows: The water enters through pipe 76, passes through 81, at the top of which it overflows through pipe 83, whence if fills the bottom seal 86, leaving finally through pipe 134. The gas passes through 56A to 82 and out through 56 which is the gas line to the instruments.

--THE STEAM FLOW METER--

The General Electric Steam Flow Meter may be explained by reference to Fig.(11). Its operation depends upon the displacement of a column of mercury by the differential pressure action of a modified Pitot tube. B is the static opening and A, the dynamic opening. These two openings are interconnected by means of a

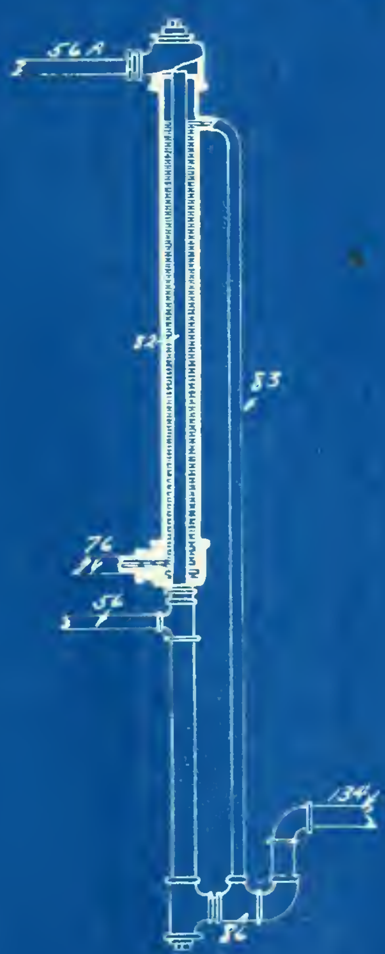


Fig. 10.

Fig. 11.

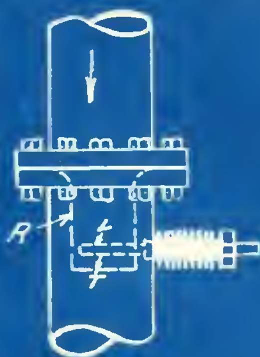


Fig. 12.

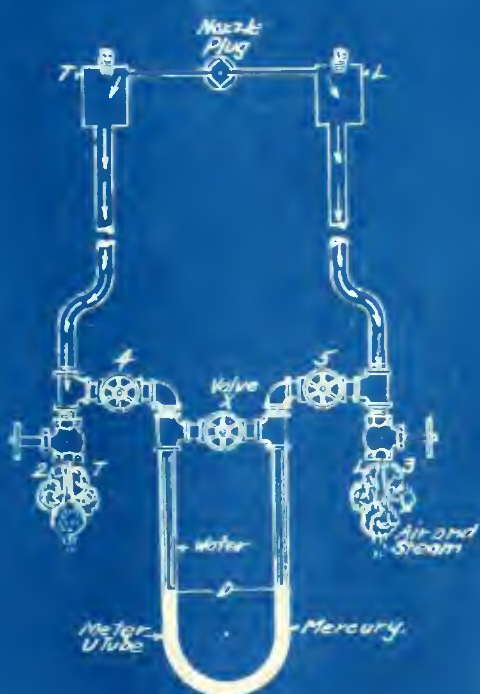


Fig. 13.

U-tube M partly filled with mercury. When there is no flow of steam the mercury columns will be at the same level and the upper portions of the tube will be filled with condensed steam. As soon as the steam begins to flow, the mercury column will be depressed as shown and the difference H will be a measure of the velocity of flow at a point in the pipe where the dynamic tube A is placed. The velocity of flow can be expressed by the equation:

$$V = K\sqrt{H\frac{d_m}{d_s}}$$

where,

d_s = density of steam in main pipe.

d_m = density of mercury in lbs. per cu. ft.

V = max. velocity of flow, ft. per sec.

K = coefficient determined by experiment.

H = difference in height of mercury levels.

To reduce the number of holes to be made in the main steam pipe, the dynamic and static openings are combined into one nozzle plug. This plug

is illustrated in Fig. (12). The plug is screwed into the main steam pipe with the arrow on the face of the plug pointing in the direction of steam flow. The dynamic openings are designated by the letter "L" or"Leading Set" and the static openings by the letter "T" or "Trailing Set". In case the velocity of the steam is too low to be accurately measured with a normal velocity plug, a pipe reducer consists of a metal cylinder with a rounded approach inserted between tem, and held in place by the two flanges of a pipe. The reducer nozzle plug is screwed in the pipe and projects through a hole in the pipe reducer itself. It extends across the throat of the reducer as shown in Fig.(12). The nozzle plugs used with pipe reducers differ in minor respects from the normal velocity nozzle plugs.

To be of practical value and to overcome difficulties which arise in the use of this principle the meter has its parts arranged as shown in Fig.(13). The steam on leaving the nozzle

plug passes into the reservoirs from their respective openings. Valves are provided at a point just before entering the reservoirs. From the reservoirs pipes lead to a place where the meter can be conveniently located. Blow off valves 2 and 3 are provided for removing air from the system. Meter valves 4 and 5 are provided at entrance to the U-tube and a cross over valve X is provided to bypass the U-tube when valves 4 and 5 are open.

The commercial form of the instrument is shown in Fig.(14). All connections are the same as shown in Fig.(13). The body of the meter is of cast iron. Fig.(15) shows an interior view of the meter body with the internal mechanism in place. The internal mechanism is shown removed from the meter in Fig.(16).

The base of the meter is about half filled with mercury, which supports the iron float in the tube. The meter pipes above the surface of the mercury are filled with condensed steam. The pressure differential, due to the flow of

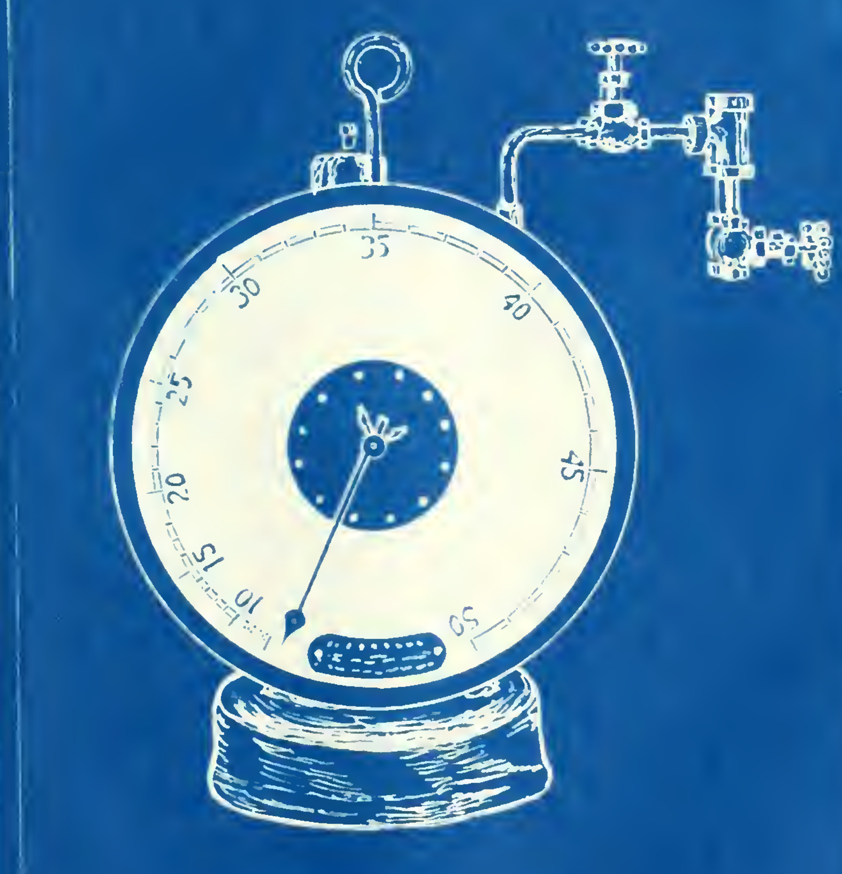


Fig. 14.

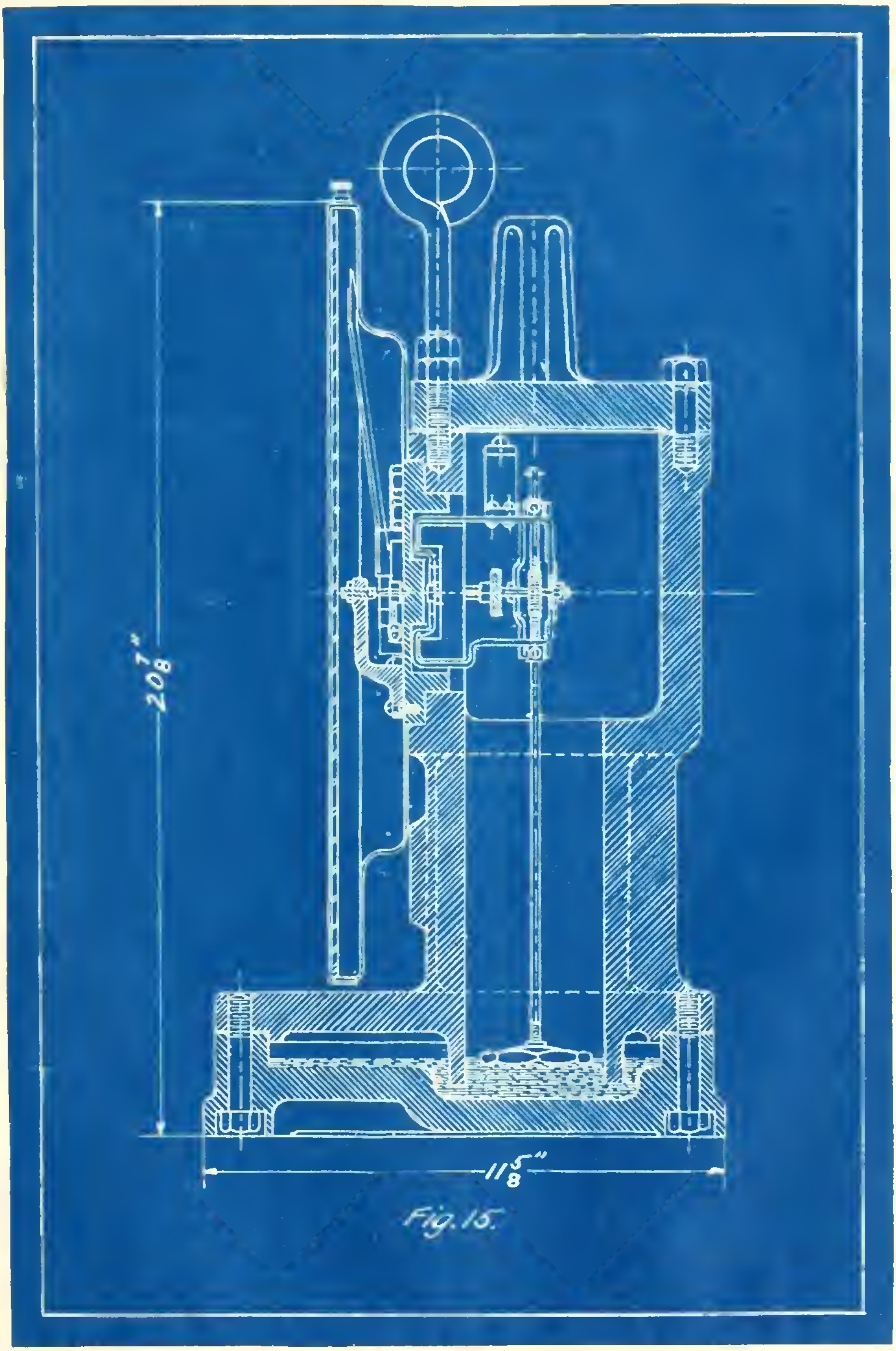


Fig. 15.

A. Float.
B. Rack.
C. Pinion.

D. Frame.
E. Guide.
F. Magnet.

Fig. 16.

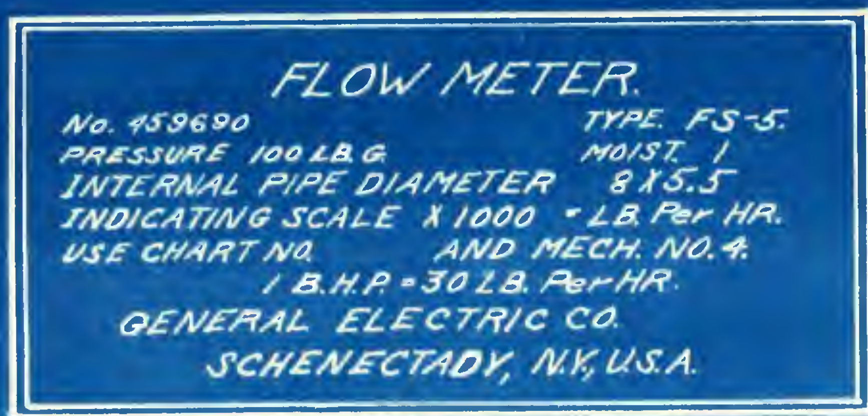
the stream being metered displaces the mercury and thereby the internal float mechanism which constitues the prime moving element of the meter. The pressure difference is conveyed from the nozzle plug to the meter by means of the pipes L and T.

For a given rate of flow, the mercury and the float will be deflected a definite distance up the tube. The float is geared by rack and pinion to a cross shaft which carries a permanent U shaped magnet as shown. The magnet poles face toward the copper cap bolted over the opening in the meter body. The external mechanism of the meter has a shaft in axial alignment with the inner shaft and carrying a similar magnet. Magnetism is used to transmit the motion from the interior to the exterior of the meter body doing away with a stuffing box and the resultant variable friction.

The indicating scale figures are based on a given combination of pipe diameter, quality

and pressure. The conditions for which the meter is calibrated is found on the name plate. The name plate set on the particular meter to be used here is shown in Fig.(17). In addition to the serial number, type, etc., the name plate gives the pipe diameter, pressure, the kind and quality of the fluid for which the indicating scale is calibrated. It shows in what units the meter is calibrated and also gives the multiplying constant to be applied to all readings of the indicating scale. The pressure stamped on the name plate means the actual steam pressure in the main at the nozzle plug, as indicated by the gauge when the barometric pressure is 29.921 in. of mercury. If the steam pressure is appreciably higher than the calibration pressure the instrument will read low and vice versa.

For steam of constant density the opening through which it flows may be made constant and the variation in velocity will be an indication of the rate of discharge. The density of the



FLOW METER NAME PLATE.

Fig. 17.

steam is seldom constant and this is the chief defect in this particular instrument which depends on a variation in velocity for its operation. The density of the steam is a function of the pressure and quality and any variation in either affects the weight of discharge.

--THE VENTURI WATER METER--

When water flows through a pipe containing a contraction like Fig.(18), the pressure at the throat B is less than at the inlet A, due to the increased velocity at B. In a properly proportioned pipe this loss of pressure is almost entirely regained at the outlet C, this in turn being due to the decrease of velocity after the water passes the thoat. These facts may be easily proved by inserting pressure gauges at A, B and C. Without increasing the working pressure, therefore, practically the same amount of water will be delivered through such a tube as through an equal length of straight pipe of the same inlet and outlet diameter.

The temporary loss of pressure at B can be accurately measured by a U-tube containing mercury, and it is found to increase approximately as the square of the throat velocity,—that is to say, if the velocity of the water at B "doubles up", the difference of mercury

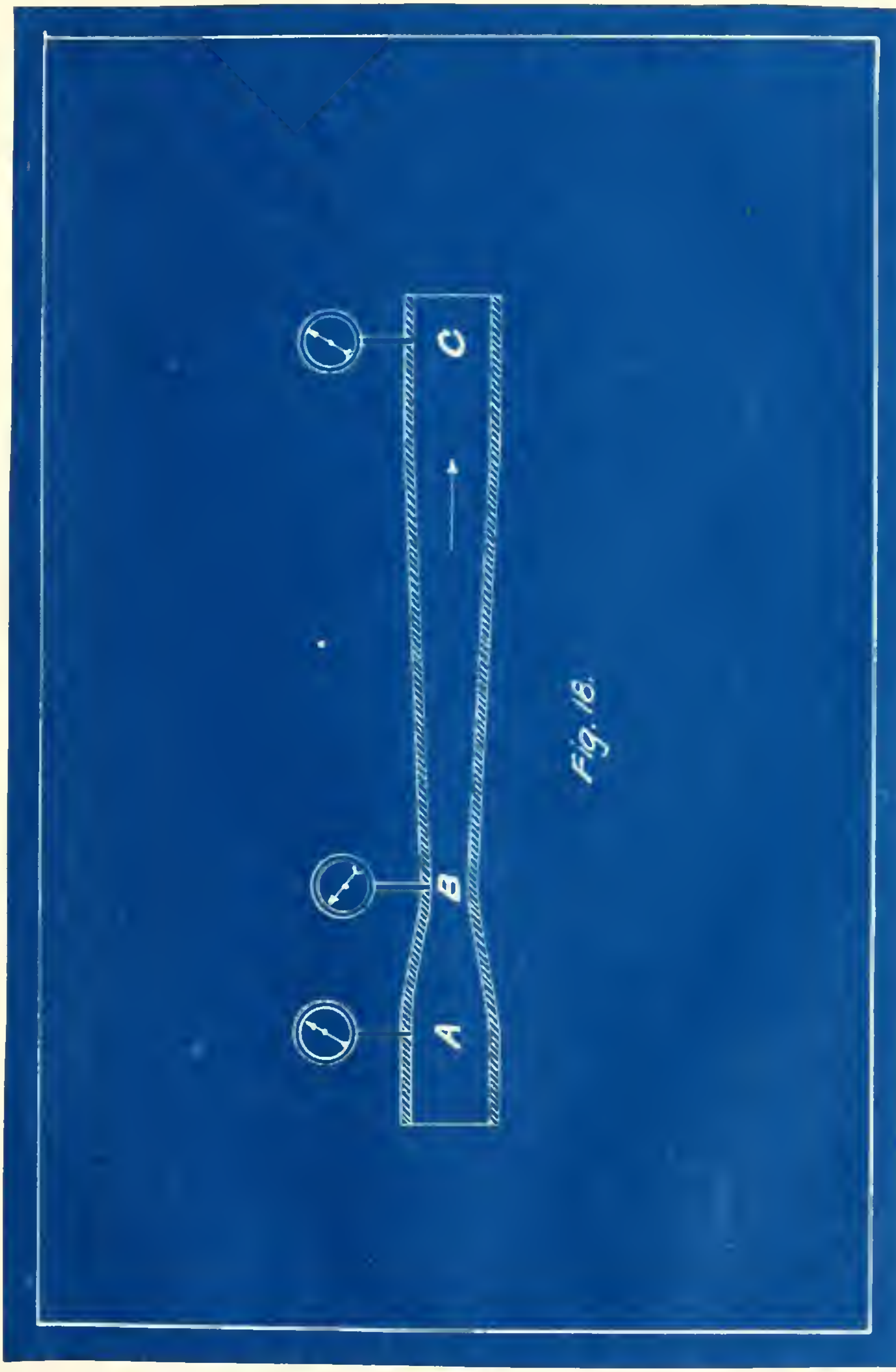


Fig. 18.

levels becomes about four times as great. The size of a Venturi Meter is expressed by the diameter in inches of the inlet end of the Meter Tube.

The indicating of the flow of water is a very simple affair, but the recording of the flow is more difficult and leads to a complicated piece of mechanism. Fig.(19) shows the internal mechanism of the Type M Recorder as used in this installation.

At the back of the register are two large, vertical wells connected at the bottom by a small pipe. One well is subjected to the inlet and the other to the throat, pressure from the meter tube, these pressures being transmitted to the meter tube by two small pipes. In each well is a heavy float resting on mercury, a part of which flows from one well to the other in direct proportion to the difference in the two pressures. Consequently one float rises as the other descends and this movement is transferred through rack and spur gearing to the indicator dial hand shaft.

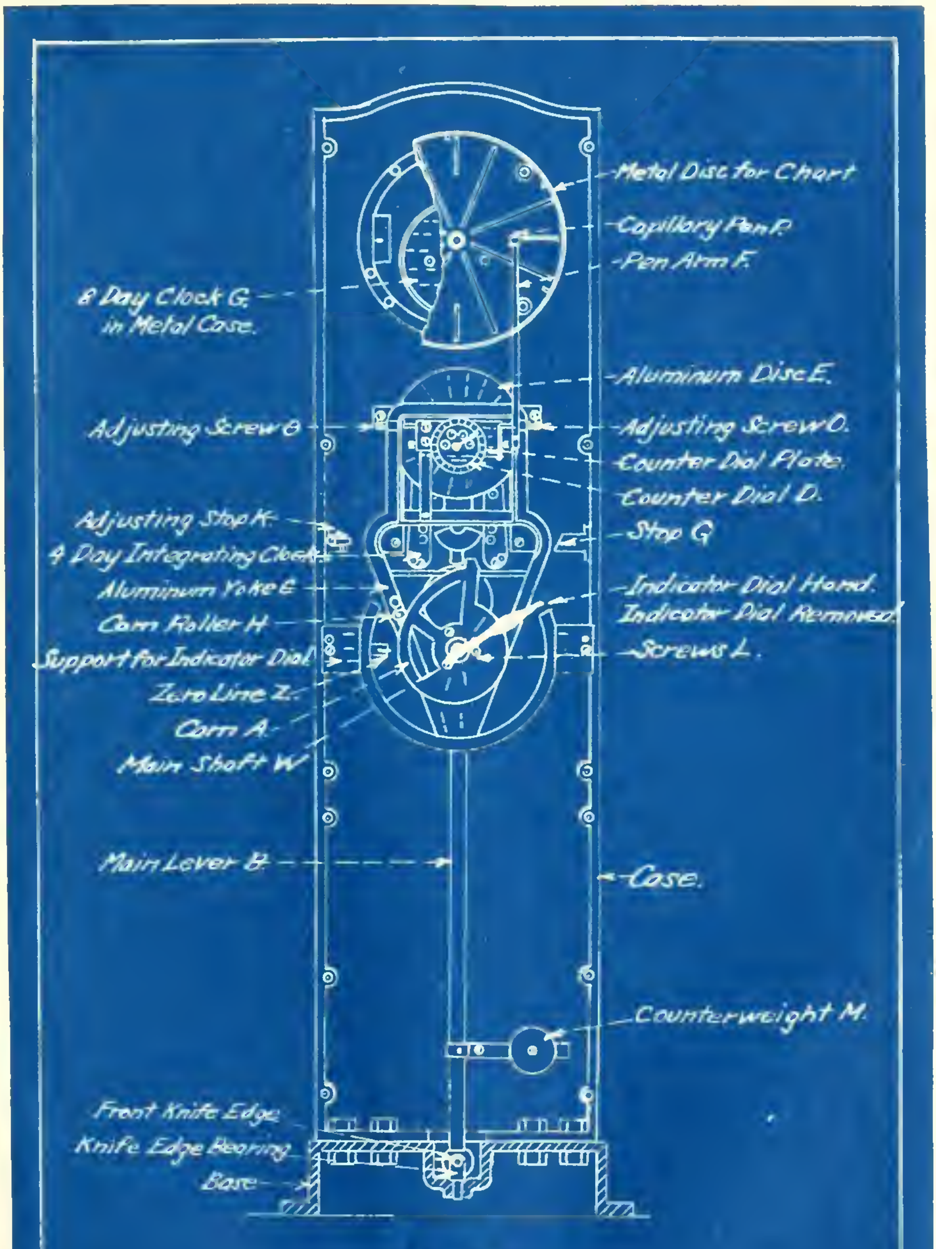

Metal Disc for Chart
Capillary Pen P.
Pen Arm F.
8 Day Clock G.
in Metal Case.
Aluminum Disc E.
Adjusting Screw O.
Adjusting Screw O.
Counter Dial Plate.
Counter Dial D.
Adjusting Stop K.
4 Day Integrating Clock
Stop G
Aluminum Yoke E
Indicator Dial Hand.
Indicator Dial Removed.
Cam Roller H
Support for Indicator Dial
Screws L.
Zero Line Z.
Cam A.
Main Shaft W
Main Lever B.
Case.
Counterweight M.
Front Knife Edge
Knife Edge Bearing
Base

Fig. 19.

A cain on this shaft controls the position of the pen on the chart, also the amount of movement of the counter dial hands. Bronze, aluminum and other non-corrosive metals enter into the construction of the interior parts. The instrument case is of cast iron.

The indicator dial is of brass, silver plated, about 11 inches in diameter and shows the exact rate of flow at the moment of observation. It is graduated in pounds per hour.

The counter dial shows the total pounds that have passed through the meter tube. When flaw occurs through the meter tube, a movement of the lower dial hand is readily perceptible. Inside the graduations of the large dial are four smaller dials, which show the registration for long periods. The dial hands all revolve in a clockwise direction, making the counters easy to read.

The chart recorder dial contains a large 24 hour chart haveing a continuous autographic

record of the rate of flow through the meter tube. The ordinary polar planimeter is not adapted for integuating circular charts, and a special form is used. The planimeter determines the total quantity of water discharged through the Venturi Meter for 24 hours or during any fraction of that time.

The indicating of the flaw is much more simple and requires only a manometer as shown in Fig.(20). This instrument shows the exact rate of flow through the Venturi Meter Tube at the moment of observation. It is based on the principle of the barometer. It contains a well filled with mercury into which dips a glass tube. The higher pressure from the inlet of the meter tube is conducted to the top of this mercury surface and the lower pressure from the throat to the interior of the glass tube. The difference in these two pressures is indicated by a single column of mercury within the glass tube. The rate of flow can be accurately observed on

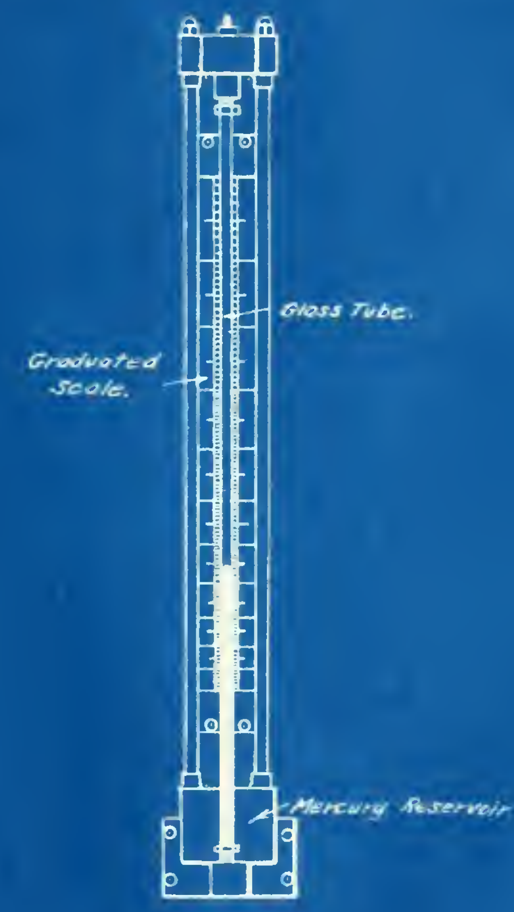


Fig. 20.

the metal scale opposite the top end of the mercury column.

--THE DRAFT GAUGES--

The simple draft gauge indicates the difference in pressure between the point to which it is connected and the atmosphere. A differential draft gauge indicates the difference in pressure between two points in the gas passages.

Ordinary draft gauges are modified forms of U-tube. As the pressures are very small, water or oil is used as the liquid in the tube. Oil has a greater uniformity of capillary attraction and minimum evaporation. The gauges are calibrated for a given oil which is usually colored. For greater accuracy in reading the pressure, one leg of the tube is inclined.

The Blonck Efficiency Meter, Fig.(22), consists essentially of two sensitive differential draft gauges, one connected between the ashpit and the furnace and the other connected between the furnace and the breeching on the

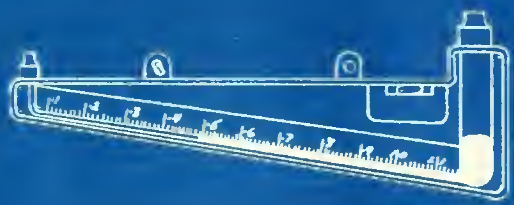


Fig. 21.

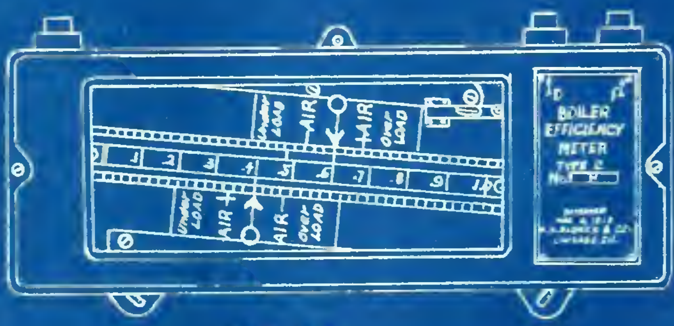

UNDER LOAD
AIR
AIR
OVER LOAD
BOILER
EFFICIENCY
METER
TYPE C
No.
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
UNDER LOAD
AIR
AIR
OVER LOAD

Fig. 22.

boiler side of the damper. The lower gauge filled with red oil shows the drop in draft through the fire or the resistance of the fuel bed; the upper gauge filled with blue oil registers the drop in draft between the furnace and the damper or the resistance through the boiler.

Two sliding indicators are arranged so that they can be set at the point of perfect firing. These indicators are marked with legends showing underload and air(+) at one side of the arrow, overload and air(—) at the other. The meter is enclosed in a heavy cast iron with a plate glass front. A level glass is also provided for leveling the meter.

The interpretation of the readings which are obtained from the meter are explained by reference to Fig.(23). The arrow marks represent the marks on the sliding scale. No.1. shows the position of the liquids in the tubes

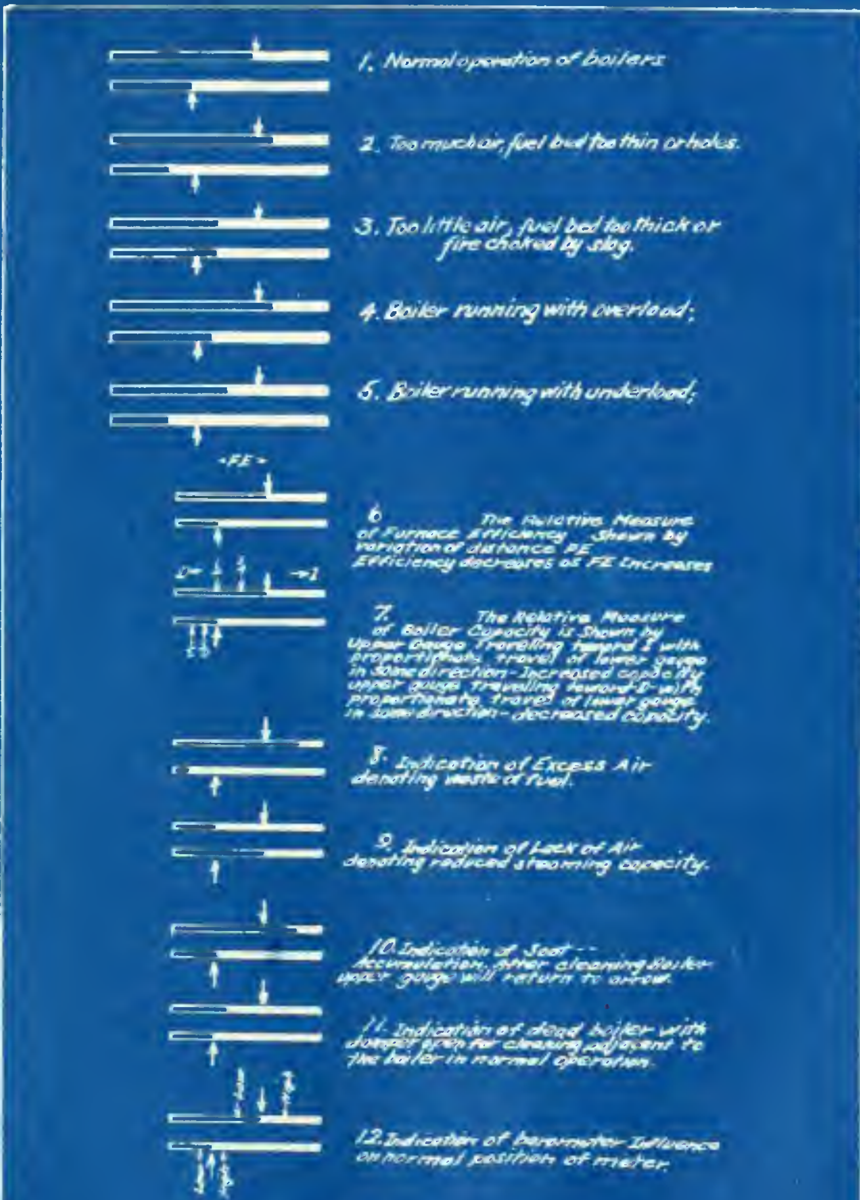

1. Normal operation of boilers
2. Too much air, fuel bed too thin or holes.
3. Too little air, fuel bed too thick or fire choked by slag.
4. Boiler running with overload;
5. Boiler running with underload;
FE
6 The Relative Measure of Furnace Efficiency Shown by variation of distance FE Efficiency decreases as FE Increases
D
I
7. The Relative Measure of Boiler Capacity is Shown by Upper Gauge Travelling toward I with proportionate travel of lower gauge in same direction - Increased capacity. upper gauge travelling toward D with proportionate travel of lower gauge in same direction - decreased capacity.
8. Indication of Excess Air denoting waste of fuel.
9. Indication of Lack of Air denoting reduced steaming capacity.
10. Indication of Soot -- Accumulation, after cleaning boiler upper gauge will return to arrow.
11. Indication of dead boiler with damper open for cleaning adjacent to the boiler in normal operation.
12. Indication of barometer Influence on normal position of meter.

Fig. 23.

under normal operation. When too much air is supplied the fluids will take a position shown in No.2. An increase of air causes increased resistance through the tubes and a higher reading. A thin fuel bed or holes reduce the resistance and cause a lower reading. Too little air will cause the fluids to take a position as in No.3. By similar analogy the fuel bed is too thick or choked by slag. An overload requires more gases to go through the tubes with consequent higher fuel bed resistance and higher differential gauge readings as in NO.4. An underload will have the reverse effect on the gauges and show up as in No.5.

It is also desirable to know the total or effective draft and for this purpose the Ellison differential draft gauge is used, Fig.(21). The gauge consists of one sensitive inclined tube connected between the ashpit and the breeching on the boiler side of the damper. The gauge is filled with red oil and shows the total avail-

able draft. A calibrated scale is provided alongside the tube to accurately indicate the draft in inches of water. The tube is placed in an aluminum shell provided with a level glass to keep the tube at the proper inclination. The Ellison draft gauge is cross connected with the ashpit and damper sides of the Blonck Meter.

--THE MILLIVOLTMETER PYROMETER--

As thermo-electric pyrometer consists of a thermo-couple, a measuring device, and wires connecting the thermo-couple and the measuring device.

If two pieces of wire of different material, for instance, one wire of copper and one of iron, are joined at one end, and heated, a small current of electricity is generated. This is known as thermo-electricity and the wires comprise a thermo-couple. The current generated is small. Wires of base metal, such as iron and nickel copper generate about 50 M.V. or fifty thousandths of a volt at 2000 deg. Fahr.

It is one of the properties of a thermo-couple that the voltage which it generates is dependent on the differance in the temperature of the hot junction, that is the one placed in the breeching and the cold junction, which is the point at which the alloy wires of the thermo-couple join the copper leads of the instrument. It is therefore particularly important that the cold junction be maintained at a constant temperature, for if a base metal thermo-couple is in use and its cold junction increases in temperature ten degrees, the decreased voltage generated by the thermo-couple will cause the instrument to read ten degrees lower. If the cold junction decreases, thepyrometer will read higher to the same extent.

The thermo-couple used in this installation is of base metal and is enclosed in a high grade wrought iron fire tube. The cold junction is brought to a plug head at one end of the tube. The copper leads from the instrument are attach-

ed to the plug head by an attachment plug as provided.

The voltage produced by the thermo-couple is measured by a high resistance millivoltmeter. By the use of high resistance, errors due to atmospheric changes in the temperature along the wiring are reduced almost entirely. The millivoltmeter scale is calibrated to read directly the temperature. The instrument consists of a permanent magnet with its pole pieces, in the fields of which a copper wound coil swings in jeweled bearings. A zero adjustment screw is provided for setting the needle to zero on the scale to take care of the variation in temperature of the cold junction.

PART V.---INSTALLATION OF APPARATUS.

--INSTALLATION OF CO_2 METER and PYROMETER--

The box containing the meter was brought to the place where the instrument was to be located. The instrument was removed from its wooden case and placed upon a platform provided for the purpose. It was rigidly fastened to the platform by means of bolts and located so that there was access to all parts. The location is as shown in Fig.(3). A diagrammatic arrangement of all parts connected to the instrument is shown in Fig.(24).

The sampling tube 88 was made of 3/4" iron pipe and cut long enough so as to extend to the middle of the stream of gas to be continuously sampled. The tube was placed in the last pass of Boiler No. 1. at a point just before the gas leaves the boiler, Fig.(4).

The preliminary filter 84 was the next thing to be connected up. This was placed at a height so as to be easily reached in order to change the filtering material. Pipe of 3/4"

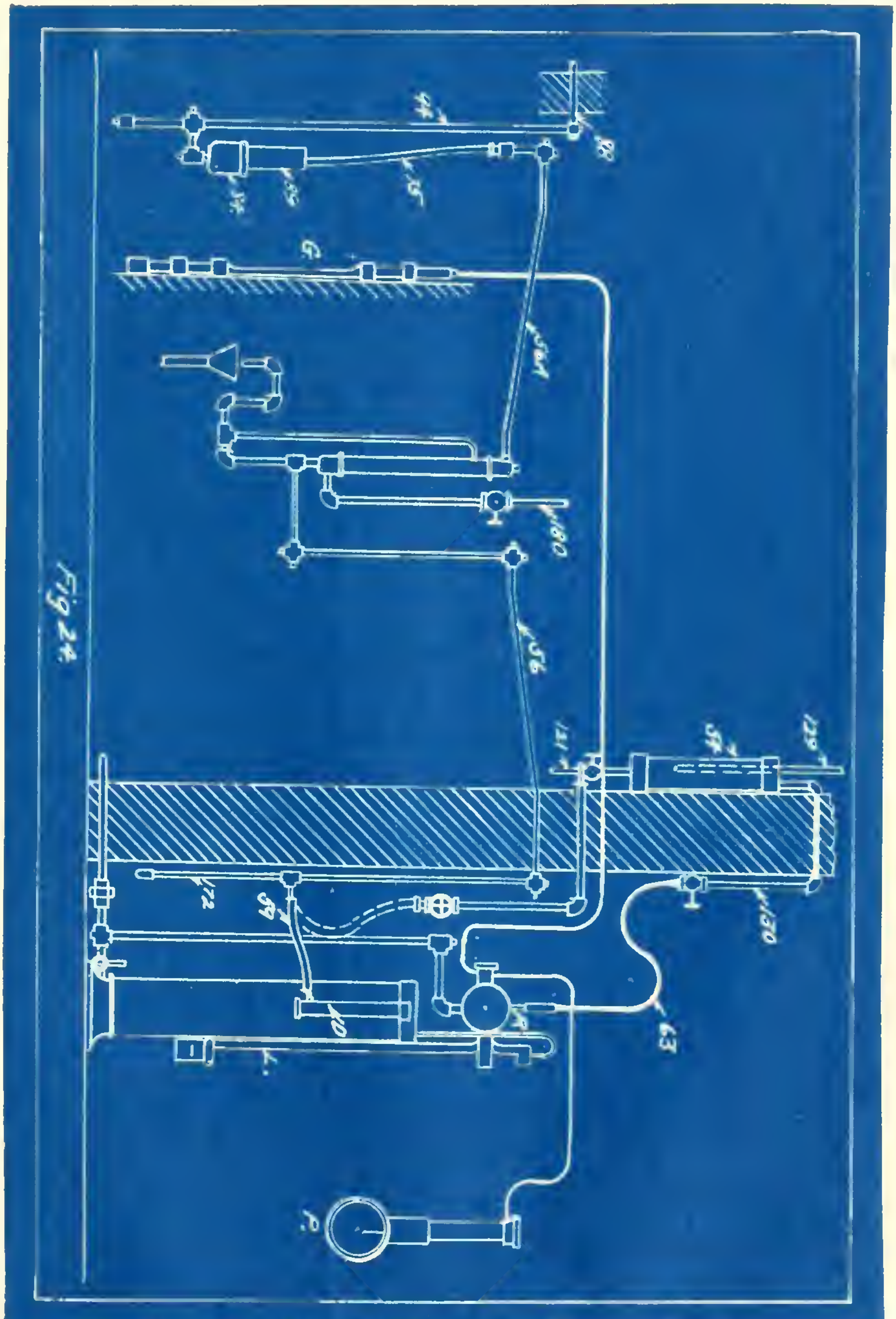


Fig 24.

size was used and tees with the open ends plugged were provided, instead of elbows, to facilitate cleaning. The filter tube 125 is sealed by bell 89, cup 84 being partially filled with thin oil to the overflow. A cross section of the filter is shown in Fig.(25).

The condenser was placed so as to occupy the lowest point in the gas line. A 1/4" iron pipe 56A was connected to the condenser from the filter and with a considerable slope toward the condenser. The flexible gas connection 75 makes it possible to lift bell 89 out of the oil seal 84. The cylindrical filter 125 can then be easily removed and replaced. The other end of the gas line was connected to line 56 of the condanser and led to a point just back of the instrument. The flexible gas connection 59 as furnished with the unit was coupled with a 1/4" nipple 58, Fig.(24), to fit the 1/4" gas line 56 from the boiler. The other end of the connection 59 was attached to filter D, Fig.(26).

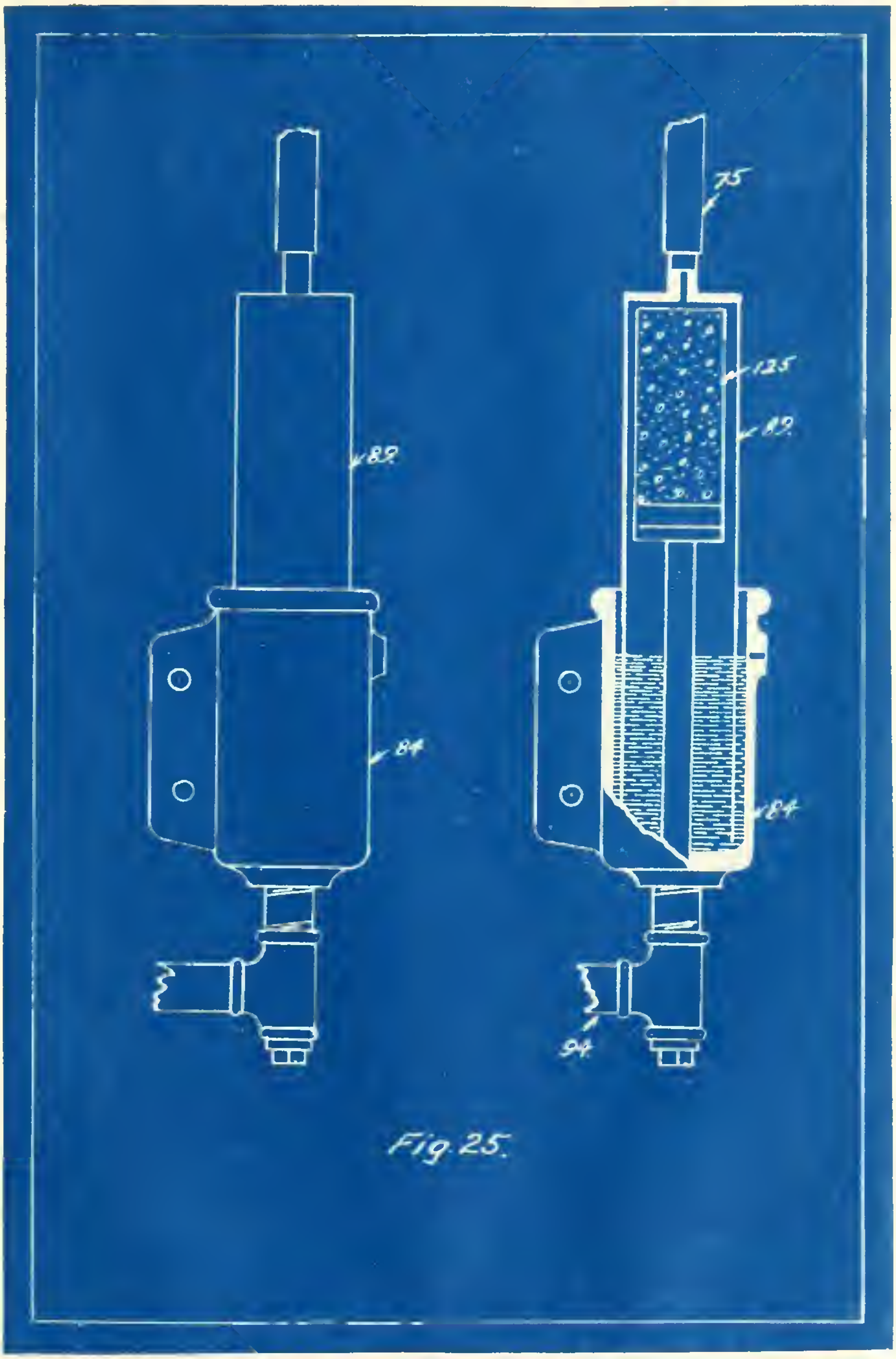


Fig. 25.

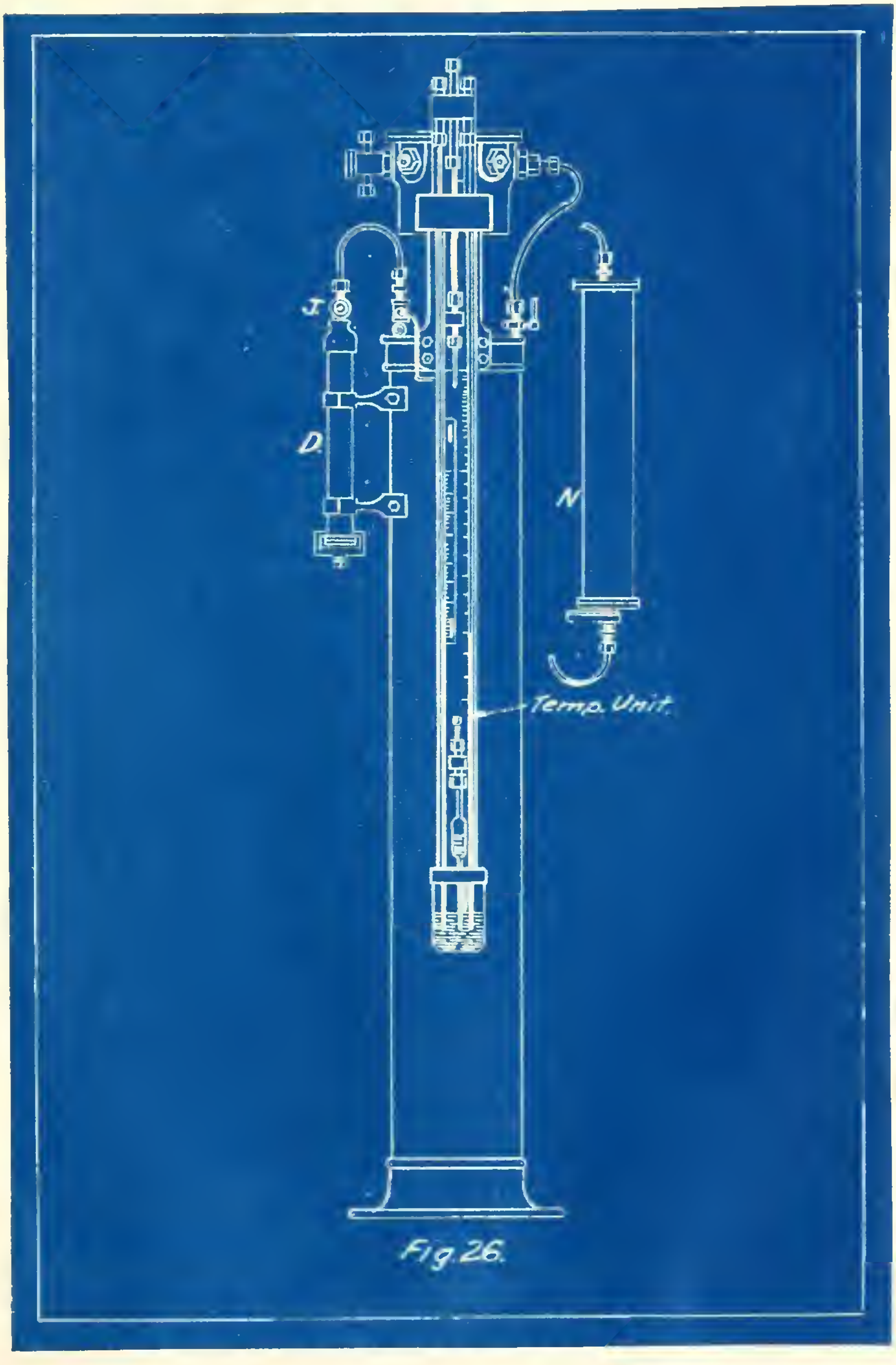


Fig. 26.

A steam connection was also provided in the line to blow out the line in case it would become plugged. Drips were also provided to bleed the line in case water might get into it.

Cold water was provided from the city main to the condenser by means of a 1/4" iron pipe 80 and provided with a valve to regulate the flow of water. The overflow from the condenser was led into a 3/4" drain line, so that the amount of water flowing from the condenser was visible to economically control its flow.

In order to provide dry steam for the aspirator of the instrument, a separator, Fig.(27) was made as shown. This was constructed of 3" pipe and 3' long with a cap on each end. A 1/4" steam supply pipe 129 was lead to within a few inches of the bottom of the separator as shown. The outlet 130 was made of 1/4" pipe fitted with a 1/4" valve. A drain pipe 121 with valve was led to the drain line so that drippings could be visible to insure dry steam. Live steam was led

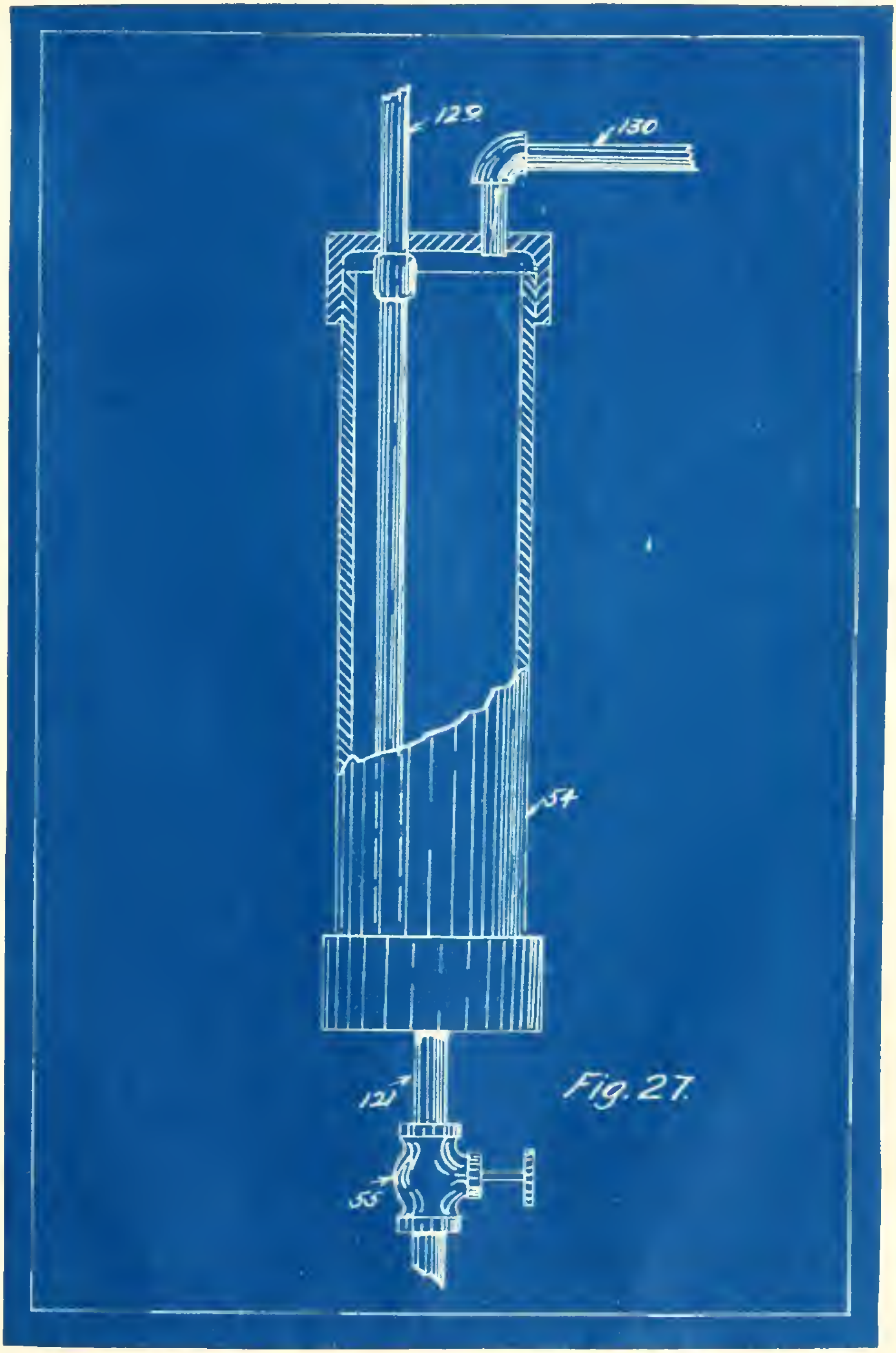


Fig. 27.

to the separator through a strainer to keep the line free from scale etc., to avoid any possiblity of the aspirator becoming clogged. A copper steam pipe 63 provided with the instrument was connected to aspirator R, Fig.(24).

Cross 50, Fig.(8), was connected to the drain line by means of 3/4" iron pipe. The drain line was led to a sewer conveniently located.

The fire tube, Fig.(9), of the pyrometer was placed in the breeching at a point where the gases leave the boiler, Fig.(4). Filter 98 was coupled on to connection 103 and a 3/8" copper tube 124 was led to one point on filter 146, Fig.(28).

The recording gauges, Fig.(30), were fastened to the wall in a vertical position close to the main instrument. The gauges were connected to the proper points on the main instruments by means of 3/16" copper tubing provided with flonges and nut on each end. One end of the tubing to the CO_2 recorder was connected to the connection at the top of the gauge and the other end to

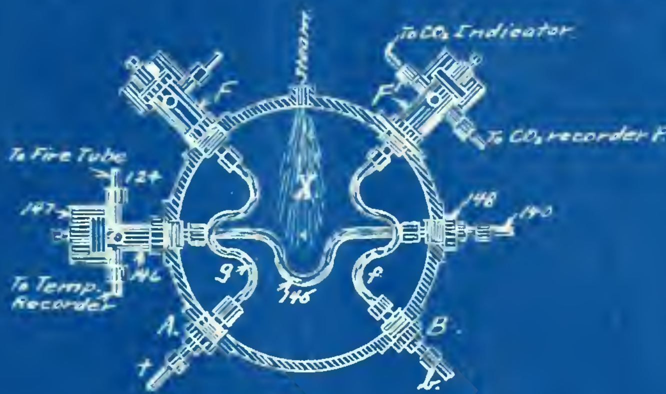

Steam
To CO₂ Indicator
F
F
To CO₂ recorder P
To Fire Tube
124
147
148
140
X
g
f
146
To Temp. Recorder
A.
B.

Fig. 28.


E
J
116.

Fig. 29.

Fig.30.

one of the connections on filter F' at steampot Fig.(28). The tubing to the temperature recorder was connected in like manner to filter 146, Fig.(28). After the recorders were set in place, cap 47 was removed by loosening clamp 48. The block of wood, which was put there to hold bell 41 in place for shipment, was removed, and mercury poured into the opening as furnished for the gauge. The contents of a small bottle of special oil was added to cover the mercury and prevent oxidation. A small rubber band was placed around the neck of the cap to make a tight joint by means of clamp 48. The pen point provided with the instrument was inserted in the pen arm and filled with ink ready for operation.

The auxilliary CO_2 indicator ---- G, Fig.(8), was fastened to the Boiler Control Board, Fig.(5). Connection was made between the indicator and a connection on filter F' at steampot by means of 3/16" copper tubing with flange and nut at each end.

Wooden cases were built around the instruments so as to keep the dust away, which is so common to the boiler room. Glass was placed on all sides to afford a view to the scales without opening the doors. The sides were made removable to allow access to all parts for repair. A view of the conpleted meter installation is shown in Fig.(31).

--INSTALLATION OF STEAM FLOW METER.--

A section of the main steam pipe from Boiler NO. 1. was removed for installing the reducer. While down, a hole was drilled and tapped for the nozzle plug. The pipe reducer being furnished blank, flange bolt holes had to be drilled to properly fit the flanges. The section was then replaced with the nozzle plug in place. The plug was so located that a straight run of eight pipe diameters preceded the leading side of the plug. The purpose of this was to obtain a steady flow without eddy currents.

The nozzle was screwed into the main so that

the arrow on the plug pointed in the direction of the flow. The two bent sections of pipe were screwed into the two holes marked "L" and "T" which lie in the same horizontal plane. The other holes "L" and "T" were closed with the two long plugs. The two valves were then screwed on to the two bent sections of pipe and the nipples into the valves. Lastly the reservoirs were screwed on to the nipples. These we placed with the ends marked "Top" at thetop. Careful attention was given to the leveling of this part of the apparatus.

The meter was located on the wall at the center of the control board Fig.(5) which is in position for direct observation by the fireman. A universal wall bracket provided with the meter was rigidly fastened to the wall by means of expansion bolts. Attention was given to the leveling of this bracket also.

The meter body was then placed on the bracket and securely fastened to it by screws provided with the instrument. The meter was connected to the reservoirs by means of 1/2" standard pipe so that pipe "L" of the meter was connected to the "L" side of the plug, and the other side "T" to "T".

With the cover plate removed, the front case

was placed in position, with the two screws extending through the ears on the body of the casting and fastened with the two thumb nuts. The indicating needle was carefully mounted in its bearings allowing a little play to avoid damage to the pivot points.

The cross over valve (x) Fig.(13) was opened and the meter filled with clean water. Ten and one-half pounds of mercury shipped with the meter was then poured into the casting. The sleeve of the internal mechanism was lowered into position in the meter body so that the hole in the bottom of the sleeve fit on the corresponding pin in the base of the meter. The sleeve was fastened in position by a small screw and washer at the top of the sleeve rod.

The float of the internal mechanism was carefully lowered into the hole in the sleeve so that the float rested on the mercury. With the meter level, full of water, disconnected from piping and cross over valve open, the indicator needle

was adjusted to zero. The rough adjustment was made by rotating the magnet on its shaft to the right or left as necessary. The fine adjustment was made by shifting the indicating scale slightly and then securely fastening it in this position. The meter was completely filled with water and the cover plate placed on pressure tight. The meter was then connected to piping and was ready for operation.

--INSTALLATION OF VENTURI MANOMETER--

The Venturi tubes, recording and integrating mechanism were installed same years previous to the present work and will not be discussed here. The only apparatus to be installed in connection with the Venturi meter is the manometer which is located on the boiler contol board.

Holes of 1/2" size were tapped into the upstream and throat sides of the 3" Venturi tube. Nipples and reducing tees were attached to accomodate four 1/4" valves. Two were placed for cutting off the supply to the manometer and two

for relieving sediment and air.

Copper tubing of 5/16" size was fitted to the valves by means of compression couplings and led to the rear of the boiler control board Fig. (5). The manometer was placed at the right hand side of the third panel as is shown in the figure. Nipples and tees were also provided to allow for the use of four 1/8" valves. Two valves are of air and sediment and two for cutting of the water supply to the manometer. The copper tubing was connected to the proper valves thus completing connections between the Venturi tube ahd the manometer. A 1/4" plug was placed in the reservoir to retain the mercury when poured in.

--INSTALLATION OF DRAFT GAUGES--

The installation of the draft gauges is best explained by reference to the digrammatic arrangement shown in Fig.(32). The Blonck meter was placed on the boiler control board just below the clock and below it was placed the Ellison differential draft gauge, Fig.(5). The gauges were leveled by means of the level glass provided on the instru-

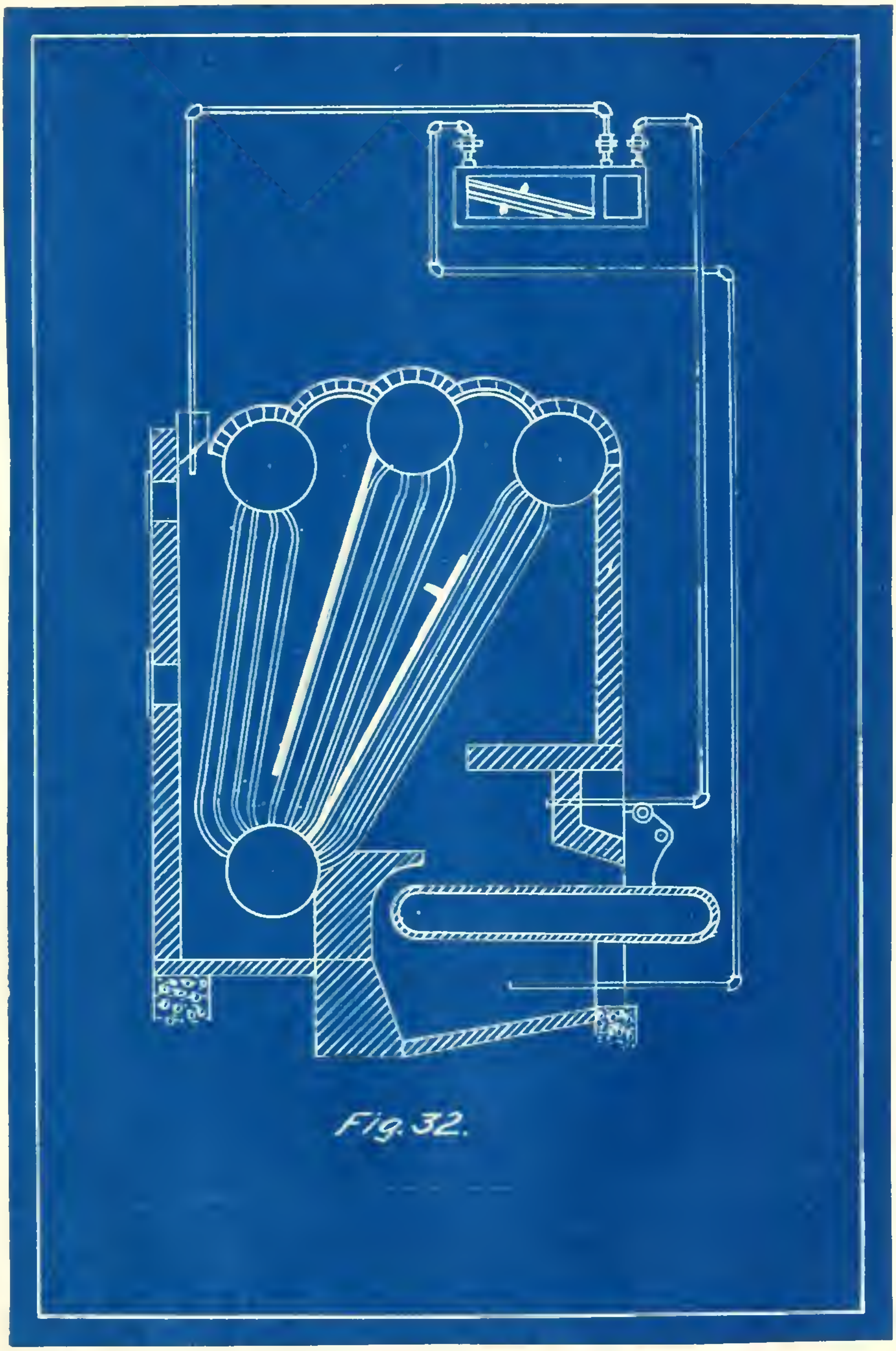


Fig. 32.

ments and securely fastened in position. Instead of using elbows to bring the connections to the back of the board tees were provided with plugs in the open ends. This allows for the filling of the gauge glasses without disconnecting the instruments.

Copper tubing, size 3/16", was used to connect the gauges to the draft tubes in the boiler. Ther vertical tube of the Ellison gauge was cross connected with the damper connection of the Blonck gauge, and the inclined tube of the Ellison gauge was cross connected with the ashpit side of the Blonck gauge. The three leads were then led to points in the furnace, boiler side of the damper, and ashpit; each to its proper place. Holes were drilled in the walls of the boiler to reach these points and 1/8" iron pipe was inserted. Over the fire a calorized tube was used. The copper tubing was fitted to the iron pipe by means of compression couplings. All joints were made tight and tested for leaks.

--INSTALLATION OF MILLIVOLTMETER PYROMETER--

The location of the fire tube for the millivoltmeter pyrometer is shown in Fig.(4). This is opposite to the fire tube of the temperature unit of the CO_2 machine. A 3/4" hole was drilled into the breeching and the fire tube inserted so that the tip of the tube projects about 12" into the breeching.

The plug attachment on the copper leads to the instrument was inserted in the plug head of the fire tube. This forms the cold junction. The wires were led over the front of the boiler to the rear of the boiler control board. The wires were kept separated and set on porcelain insulators to prevent grounding.

The bracket supplied with the millivoltmeter was regidly fastened to the wall in the rear of the boiler control board by means of expansion bolts. The millivoltmeter was placed on the bracket and is located at the lower left hand corner of the board. The plus side of the instrument was connected to the plus wire of the leads.

PART VI.--OPERATION OF APPARATUS.

25.Uehling CO_2 Meter and Pyrometer.

26.G.E.Steam Flow Meter.

27.Venturi Water Meter.

28.Draft Gauges.

29.The Millivoltmeter Pyrometer.

--OPERATION OF THE CO_2 METER AND PYROMETER--

The operation of the meter can be best explained by refernece to Fig.(8). Opening valve 1 starts the aspirator R, a vacuum is created in chamberC", which causes the flow of gas through the system. An excess of gas enters through 59, D, and aperture E into p and the quantity not required for analysis escapes through cc' into C" direct. A continuous sample flows from p to F, from F into g where, surrounded by the exhaust steam from aspirator R. It is heated to 212 degrees, thence passes through aperture A and through t into the absorption chamber N, where the CO_2 is absorbed by the caustic. From the absorption tube the remaining gas flows through e and F' into f where it is again heated to 212 degrees, thence passes through aperture B and by way of bb' into chamber C" from where it is continuously removed by the aspirator together with all other gases entering the chamber.

The water in the manometer tube vv shows the height fo water in the regulator H above the line

xx' and must be kept above the 48" index v.The water level in glass S shows the 6" suction, and the water level in the U-bulb M shows the resistance in the gas line and filters plus the chimney draft.

With all connections made and regulator H filled with 11-1/2 gallons of water, the water levels must be adjusted. The recording line is cut off by closing cocks 4 and 2. J nad 8 are opened and steam x is turned on through the aspirator R by means of valve 1. To insure dry steam valve 55 must be giving off vapor. Cock 5 is now gradually opened until the manometer S registers at the pointer A large bottle I full of water is placed on bracket 120 at the back part of the instrument. The rubber tube attached tp short copper tube n is placed to extend into the water. When the water has risen to the pointer behind bulb S cock 5 is in proper position. Water column V is now noted. If the water has risen about 1" above index R sufficient water

is in regulator H. If the water is below index R moremust be added by opening cock 6 until the water column is about 1" above index v. Cock 6 is then closed. If on the other hand water column V is more than 1" above index, water must be drawn out by opening cock 7 and closing valve 1 at successive intervals until the water column V is approximately 1" above index v. The water column should not be allowed to fall below the index.

U-bulb M is filled with water until there is about 4" of water in the tube and is attached to the rubber tube on the copper tube 117. Copper tube 117 extends from filter D.

The caustic carton must next be inserted. Wing nuts 23, Fig.(33) are loosened at the bottom of carton holder N and the cap 18 pushed to one side. A number of holes are punched into each end of the carton and placed in the holder with the part marked "Top" at the top. The round rubber ring is placed between the holder N and the cap and the wing nuts 23 are screwed up. The rubber ring prevents the gas from passing the carton 14 and the holder N and at the

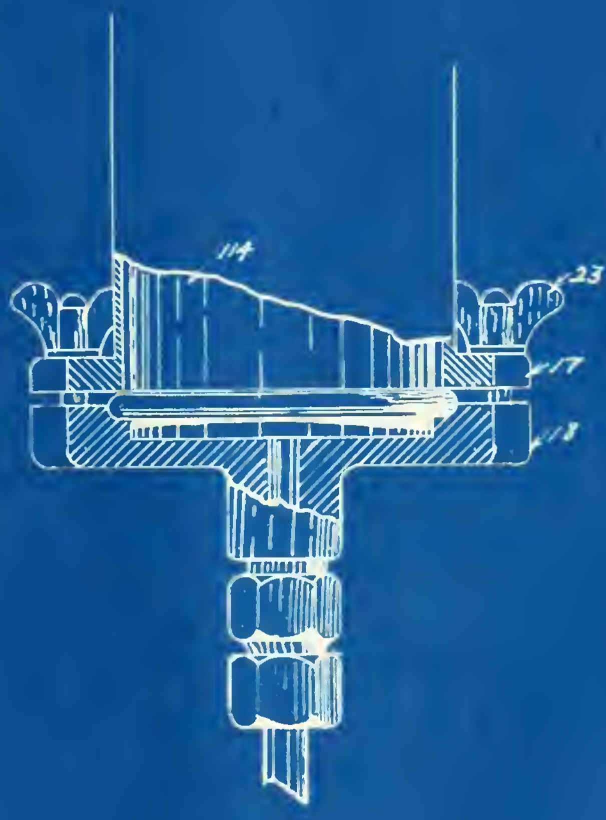


Fig. 33.

same time makes a joint between 17 and 18, Fig. (33).

Vessel K is filled with water until the bottom of the rod 31 is just touching the water. Cocks 4 and 2 are now opened and L, G, and P will register somewhere near zero. Before adjusting for zero, the instruments are tested for leaks. By closing cock 2 the pressure in the line is much reduced, and the level at L climbs up; when it reaches a point about 6" above the 20 percent line, cock 4 is closed. The levels in L,G, and P should remain at a standstill unless there is a leak in the instrument. If the levels remain constant for several minutes, the adjustment is satisfactory for practical working.

If a leak is indicated, it will probably be in the connection made when setting up. Each unit can be tested independently. A leak is most likely to occur in the joints of the absorption chamber N which holds the caustic carton. Before looking elsewhere for a leak, it is good practice

to make sure that the absorber N is properly placed, and that the rubber rings are in the proper position. If a connection is taken apart, care must be taken to put it back tight.

To blank off the boiler-room gauge, disconnection is made near filter F'. The opening is closed by a copper blanking disc and nut. The machine is tried again for leaks. To test the indicator alone, the tubing is disconnected at 15 and the opening placed in the mouth. The column of oil is sucked up until it reaches 2- per cent and the opening is closed with the tongue. If the column stands steadily the leak is in the tubing or connections; if not, the leak is in the indicator itself in the joint between top piece 15 and the glass tube. This top piece with glass tube can be removed by loosening the set screw. The joint between the glass tube and the top piece is made by means gasket on the glass tube with a washer and nut. In the same manner the recording gauge is blanked off and tested.

To test the recorder alone, the tubing at the top of the recorder is disconnected. In removing the recorder name plate, the counterweight can be lifted up until the pen point reaches the 20 per cent line. If, on closing the opening at the top of the gauge, the pen does not sink,then there is no leak. The most likely leak is about cap 47. There is small chance for a leaky valve, but should a valve leak, the leak can be stopped with vaseline.

In adjusting for zero, the machine is run on air for about 15 minutes. The levels in S,V, and K, are noted so that they are correct. By closing valve 4 for an instant to allow the liquid in gauge L to drop; and noting the position, for a few times, at which it comes to rest, adjustment can then be made. The scale on the instrument is moved to make its zero point at the water level in L, the small pen of gauge P is moved on its support so that it will register correctly, and the boiler-room gauge is adjusted

by twisting reservoir 16.

By closing cock 8 the instrument is thrown on the gas and the CO_2 content will register. Too great a suction on manometer M is most likely due to filter 125 being clogged. In continuous running the condition of the carton N is told by the position of the zone of highest temperature upon it. The gas combines with the caustic with an evolution of heat, and this heat zone is a fresh carton will be where teh gas enters.

The temperature unit is tested for leaks in a manner similar to that above described. To make sure that there are no leaks in the joints made, cock 99 is closed Fig.(9). Cock O is then opened. This will cause the temperature water column on the instrument, Fig.(26) to rise. When the water has risen to 3000 degrees and cock O is closed, the water column will come to rest if the unit is tight. If cock O and 99 is then opened the machine will show the proper temperature. If there is any difference in the readings between the machine and recorder, the pen of the recorder

can be adjusted to correspond by means of the adjusting screw.

The clocks should be wound daily. Filter 125 should be replaced as necessary, depending on the condition of the flue gas sampled. If there is any discrepancy between the indication of the recording gauge and that of the water column at L, a discrepancy most apt to occur when the CO_2 content is between 10 and 15 per eent, it will be necessary to set the gauge at these points, correcting for the difference, rather than at zero. The difference will not involve an indication of more than 0.5 per cent of CO_2.

After same time of running, difference is in indications may appear. If the water level in bulb S is high, the water level in K should be noted if it is right. If the level in bulb S is still high after adjusting valve 5, aperture E of cock J may be dirty, Fig.(29). If cleaning aperture E does not bring the 6" suction down to the index, then the cotton filter

D may be packed too tightly or may have gotten wet from the water in the U-bulb M. To clean filter D, it is opened at the bottom. When clean cotton is replaced, it must be put in loosely.
If the suction bulb is low after adjusting valve 5, coc J should be tried to see if it is loose and that the connecting points of copper tubes u and l are tight.

Each time a new carton is inserted test for leaks and adjustment of zero should be made. The cartons have different resistances and each new carton may change the zero adjustments slightly. Also in course of time the zero may get so high as not to be reached by the sliding scale. The variation is due to aperture A or filter F being clogged. The cotton in filter F should be changed and a good joint made in replacing the cap. If the zero is still high, aperture A should be removed, Fig.(34) and (35). The aperture piece should be held under a jet of dry steam and allowed to play on the platinum center of the aperture piece for 15 to 20 seconds on each side. The tiny hole should not be touched with

Fig. 34.

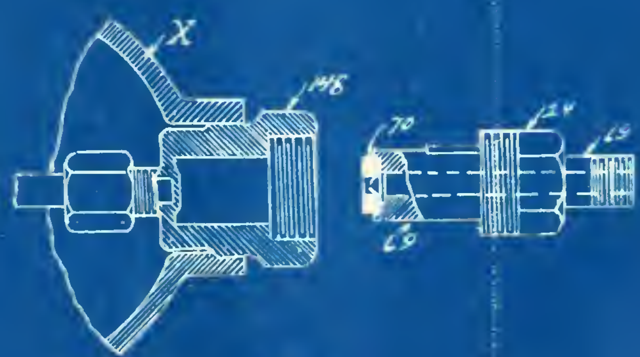


Fig. 35.

anything, as around its edges is a selvage that may be bent over, thus changing the sixe of the arifice. The aperture piece should be replaced in the holder in its original position.

If the column in the U-bulb fluctuates there is probably water in the gas line. The water can be trapped by cocks placed in the law points in the line.

--OPERATION OF STEAM FLOW METER--

For perfect operation all air must be removed from the pipes and completely filled with water. With pressure in the main pipe and cross over valve open, the two blow-off valves and meter valves were opened, Fig.(13). The valves "L" and "T" at the nozzle plug were carefully opened about 1/4 turn so that the steam slowly drove all air out of both pipes and flowed out of blow-off valves thus preventing re-entrance of air. While the steam was blowing blow off valves were clased and valve "T". Time was allowed for the pipes to cool sufficiently to show that the steam flowing in slowly through valve "L" condensed and filled both pipes with water.

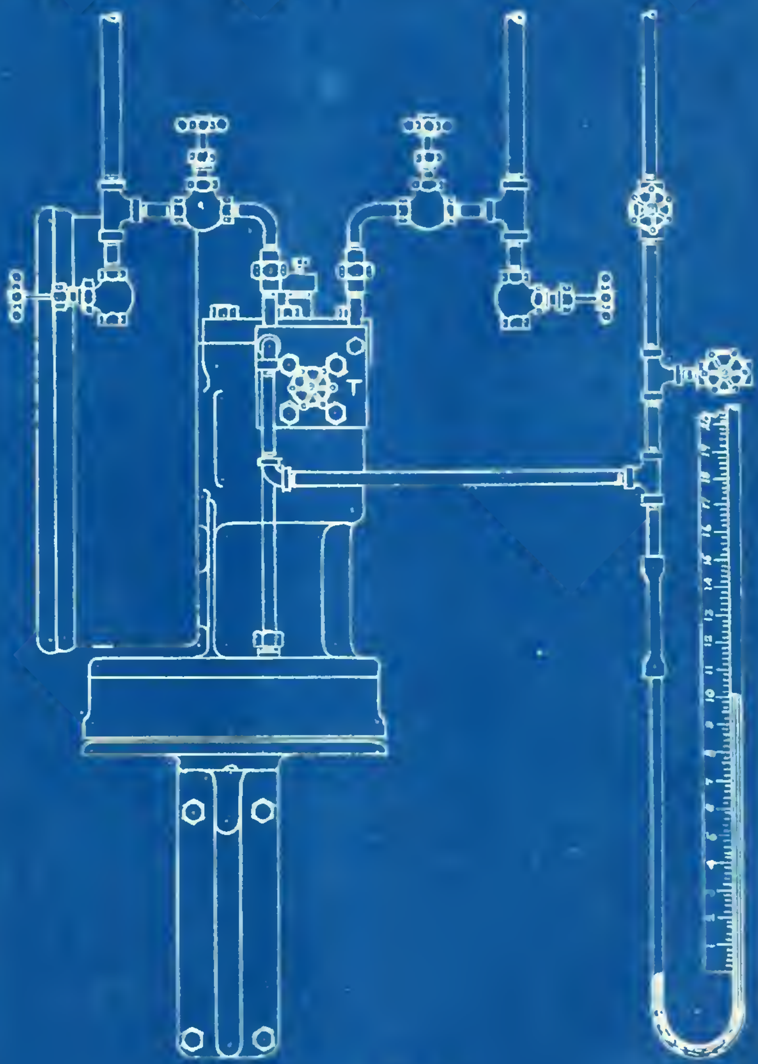
Valve "L" was then opened wide and cross over valve closed. Finally valve "T" was opened. The meter was then checked by the water column test to see if it properly registered the flow. In calibrating the meter its piping need not be disturbed and a method of testing is shown in Fig. (36). The reservoir valves are closed, cross over valve open and plugs removed from the reservoirs. The glass water column tube is connected to the hole directly beneath the "L" pipe on the cross over valve block. The plug from the cap on the meter cover is removed to establish zero on the "T" side. The glass tubing is filled with water up to the zero point, and a rule provided to show the height of water.

The scale is provided with three marks corresponding to the water columns given in the table below.

WATER COLUMN INCHES

SCALE MARKS

1	2	3
2.59	9.59	20.75



Water Column Test

Fig. 36.

If the meter is in calibration the indicating needle will register the corresponding points given as the water level is elevated from point to point.

--OPERATION OF VENTURI MANOMETER--

All connections having been made and tested for leaks, the mercury was poured into the reservoir of the manometer to the zero point of the scale. All valves being closed, the two valves at the Venturi tube leading to the manometer are opened. This brings the water to the valves at the manometer. With the valves at the manometer closed, the two sediment and air valves are opened. When the system is free from air the manometer valves are opened and the air in the manometer is drawn out. The sediment and air valves are then closed and the manometer scale will indicate the flow correctly. No attention is required when once in operation.

--OPERATION OF DRAFT GAUGES--

The plugs were removed from the tees at the gauges and blue oil was put into the top glass of

the Blonck meter through the openings until the gauge read zero when level. In like manner red oil was put into the lower gauge of the Blonck meter and Ellison gauge. The plugs being replaced and tight, the draft gauges read the proper amount. The sum of the readings on the two gauges of the Blonck meter should be equal to the reading of the Ellison gauge. This serves as a useful check on its operation.

The sliding scales are next adjusted for the point of perfect firing. They are adjusted at best operating conditions, for average load on the boilers. The best adjustment results when: (1) there is a good white fire, (2) the grate is well covered, (3) the CO_2 is high, there is a low draft over the fire, and, (4) there is a high pressure drop between fire and damper. Little or no attention is required when the gauges are once in operation.

--OPERATION OF THE MILLIVOLTMETER PYROMETER--

The operation of the millivoltmeter pyrometer is continuous while the boiler is in operation

and the only attention required is the zero adjustment. When the leads are disconnected from the fire tube at the plug head the instrument should read zero. If this is not the case the adjustment screw on the instrument is turned to bring the needle to zero. It is necessary to do this occasionally as the needle will read high or low by the amount it is out of adjustment.

After some time it is necessary to again calibrate the instrument. This is done by comparison with the readings of a standard thermocouple. The standard thermocouple is placed in one end of an electric furnace and the thermocouple to be calibrated in the other. The temperature in the furnace is gradually increased and the readings compared. A correction curve is then plotted.

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